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FOREWORD

The Quarterly Bulletin is designed primarily for the information of Canadian industry, universities, and government departments and agencies. It provides a regular review of the interests and current activities of two Divisions of the National Research Council Canada:

(1) Division of Mechanical Engineering and (2)
National Aeronautical Establishment.

Some of the work of the two Divisions comprises classified projects that may not be freely reported and contractual projects of limited general interest. Other work, not generally reported herein, includes calibrations, routine analyses and the testing of proprietary products.

Comments or enquiries relating to any matter published in this Bulletin should be addressed to: *DME/NAE Bulletin, National Research Council Canada, Ottawa, Ontario, K1A 0R6*, mentioning the number of the Bulletin.

AVANT-PROPOS

Le Bulletin trimestriel est conçu en premier lieu pour l'information de l'industrie Canadienne, des universités, des agences et des départements gouvernementaux. Il fournit une revue régulière des intérêts et des activités actuelles auxquels se consacrent deux Divisions du Conseil national de recherches Canada:

Division de génie mécanique
Établissement aéronautique national

Quelques uns des travaux des deux Divisions comprennent des projets classifiés qu'on ne peut pas rapporter librement et des projets contractuels d'un intérêt général limité. D'autres travaux, non rapportés ci-après dans l'ensemble, incluent des étalonnages, des analyses de routine, et l'essai de produits de spécialité.

Veuillez adresser tout commentaire et toute question ayant rapport à un sujet quelconque publié dans ce Bulletin à: *DME/NAE Bulletin, Conseil national de recherches Canada, Ottawa, Ontario, K1A 0R6*, en faisant mention du numéro du Bulletin.

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A THEORETICAL FORMING LIMIT FOR FORGING OF RATE-SENSITIVE, NON-WORK-HARDENING MATERIAL

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SUMMARY

Theoretical forming limit diagrams are presented for rate-sensitive forging based on a previously proposed mathematical model of localized thinning and fracture. The diagrams show similar characteristics to those for non-rate-sensitive materials, which have been supported to some degree by experimental results. However, the diagrams predict much higher strains at fracture than for non-rate-sensitive, work-hardening materials, as expected.

There is no experimental evidence to support the theoretical results as yet, but the model could provide a useful basis for future experimental work and discussion.

SYMBOLS

$\epsilon_{r,\theta,z}$	strains in the radial, circumferential and axial directions
$\dot{\epsilon}_{r,\theta,z}$	strain rates in the radial, circumferential and axial directions
$\bar{\epsilon}$	equivalent strain
$\dot{\bar{\epsilon}}$	equivalent strain rate
$\sigma_{r,\theta,z}$	stress in the radial, circumferential and axial directions
$\bar{\sigma}$	equivalent stress
f	damage factor = t_g/t
g	subscript to refer to material in the thinned section
k	strain rate ratio = $-\dot{\epsilon}_z/\dot{\epsilon}_\theta$
m	strain rate sensitivity index
r	stress ratio = σ_z/σ_θ
t	thickness of model element

INTRODUCTION

In general, complex metalworking operations such as forging and sheet metal forming are more of an art than a science, especially with regard to the amount and complexity of forming that can be achieved with a particular material. Perhaps the most advanced concept related to this aspect of forming is that proposed by Keeler and Backofen (Ref. 1) for sheet metal forming, namely the forming limit diagram. By examining the fracture strain states in various biaxial stretch forming

operations, it is possible to find a critical strain locus, as shown in Figure 1, which divides a region of strain states which produce failure from states which do not.

This concept has recently been applied to axisymmetric shapes by Kuhn, Lee and Ertuk (Ref. 2) who produced forming limit diagrams for several steels in the tension-compression quadrant. They found that a linear relationship existed between the tensile and compressive surface strains at fracture and that the slope of this line on the compressive versus tensile strain axes is one half. It may be noted that it is a combination of strains, rather than the value of any one strain, which governs fracture.

Lee and Kuhn (Ref. 3) proposed a fracture model for axisymmetric shapes based on the concept of Marciniak and Kuczynski (Ref. 4) of localized thinning of material around an inhomogeneity. The predictions of this model fit the experimental data quite well.

The above theories do not apply directly to rate-sensitive materials. With a non-work-hardening rate-sensitive material, the flow stress is independent of the strain but is a function of the strain rate. The forming pressure and complexity are therefore a function of the rate of forming and the strain rate sensitivity rather than the total deformation and work-hardening rate.

Following the analysis of Lee and Kuhn, it is possible to derive a theoretical formability diagram for non-work-hardening, rate-sensitive materials. This may have some practical use in isothermal forging in view of the recent move to this type of forming for high strength nickel and titanium base alloys in the aerospace industry (Refs 5, 6). These materials can show rate-sensitive, non-work-hardening behaviour at high temperatures and low strain rates (Ref. 7).

MODEL

Lee and Kuhn considered the upsetting of a circular cylinder as shown in Figure 2(a) in terms of surface strains at a point such as A. It was assumed that there would be surface inhomogeneities at such a point such as voids, inclusions or compositional changes. It was further assumed that these inhomogeneities could be represented as thinned sections as shown in Figure 2(b) and (c). Two models were considered; an 'R-model', Figure 2(b), which represents an inhomogeneity in the radial direction and a 'Z-model', Figure 2(c), which represents the axial direction. The strength of the inhomogeneity is indicated by the ratio of thicknesses, $t_g/t = f_o$.

In Lee and Kuhn's model, as the cylinder is compressed, the thinned sections change in thickness more rapidly than the surrounding material under certain conditions, the rate of change being governed by the strain ratio and material parameters such as f_o and the work-hardening rate. The limiting condition, representative of final fracture, was taken as the point at which $f \rightarrow 0$, i.e. when this section thins to zero thickness.

The model used in the present analysis is very similar, the difference being the change from a work-hardening, non-rate-sensitive material to a non-work-hardening, rate-sensitive one. Then the rate of thinning of the inhomogeneity relative to the surrounding material is governed by the strain (or strain rate) ratio and f_o as before and the strain-rate sensitivity index rather than the work-hardening exponent.

ANALYSIS

The present analysis is based on the following major assumptions: (a) the material is isotropic and incompressible during deformation, (b) it does not work harden nor soften, (c) the surface strain-rate ratio around the point of the inhomogeneity remains constant during the deformation and (d) the flow stress may be represented by $\bar{\sigma} = c\dot{\bar{\epsilon}}^m$.

If the surface strain-rate ratio is defined as

$$k = -\dot{\epsilon}_z/\dot{\epsilon}_\theta \tag{1}$$

then
$$\dot{\epsilon}_r = (k-1)\dot{\epsilon}_\theta \tag{2}$$

and the surface strains can be written

$$\begin{aligned} \epsilon_z &= -k\epsilon_\theta \\ \epsilon_r &= (k-1)\epsilon_\theta \end{aligned} \tag{3}$$

Thus the equivalent strain rate, $\dot{\bar{\epsilon}}$, which is defined as

$$\dot{\bar{\epsilon}} = \sqrt{\frac{2}{9}}\left[(\dot{\epsilon}_r-\dot{\epsilon}_\theta)^2 + (\dot{\epsilon}_\theta-\dot{\epsilon}_z)^2 + (\dot{\epsilon}_z-\dot{\epsilon}_r)^2\right]^{1/2}$$

can be written

$$\dot{\bar{\epsilon}} = \frac{2}{\sqrt{3}}\,\dot{\epsilon}_\theta\,(1-k+k^2)^{1/2} \tag{4}$$

The Levy-Mises relationships may be written

$$\delta\epsilon_r = \frac{\delta\bar{\epsilon}}{\bar{\sigma}}\left(\sigma_r - \frac{1}{2}\,(\sigma_\theta+\sigma_z)\right) \tag{5a}$$

$$\delta\epsilon_\theta = \frac{\delta\bar{\epsilon}}{\bar{\sigma}}\left(\sigma_\theta - \frac{1}{2}\,(\sigma_z+\sigma_r)\right) \tag{5b}$$

$$\delta\epsilon_z = \frac{\delta\bar{\epsilon}}{\bar{\sigma}}\left(\sigma_z - \frac{1}{2}\,(\sigma_r+\sigma_\theta)\right) \tag{5c}$$

Substituting Equation (3) into Equation (5c) and combining with Equation (5b) yields

$$\frac{\sigma_z}{\sigma_\theta} = \frac{2k-1}{k-2} = r \tag{6}$$

The equivalent stress, $\bar{\sigma}$, is defined as

$$\bar{\sigma} = \frac{1}{\sqrt{2}}\left[(\sigma_r-\sigma_\theta)^2 + (\sigma_\theta-\sigma_z)^2 + (\sigma_z-\sigma_r)^2\right]^{1/2}$$

If we consider an element near the surface, then $\sigma_r = 0$. Thus, using Equation (6), the equivalent stress may be written

$$\bar{\sigma} = \sigma_\theta(1-r+r^2)^{1/2} \tag{7}$$

In the region of the thinned section, equilibrium in the circumferential direction requires that

$$t_g \sigma_{\theta g} = t\,\sigma_\theta$$

or

$$\sigma_{\theta g} = \sigma_\theta / f \tag{8}$$

If σ_z can be assumed to be the same in the thinned section as in the surrounding material, then the equivalent stress in the thinned section, $\bar{\sigma}_g$, can be obtained from Equations (6) and (8) as

$$\bar{\sigma}_g = \sigma_{\theta g}(1 - rf + r^2 f^2)^{1/2} \tag{9}$$

Eliminating $\sigma_{\theta g}$ from Equation (9) using Equations (7) and (8) yields

$$\bar{\sigma}_g = \bar{\sigma}\,\frac{(1 - rf + r^2 f^2)^{1/2}}{f(1 - r + r^2)^{1/2}} \tag{10}$$

The equivalent stress-equivalent strain-rate relationship may be written

$$\bar{\sigma} = c\dot{\bar{\epsilon}}^m \tag{11}$$

Combining Equations (10) and (11) gives

$$\dot{\bar{\epsilon}}_g = \dot{\bar{\epsilon}}\left[\frac{1 - rf + r^2 f^2}{f^2(1 - r + r^2)}\right]^{1/2m} \tag{12}$$

Then for an incremental time interval, Δt, the increment in the equivalent strain in the thinned section will be

$$\Delta\bar{\epsilon}_g = \dot{\bar{\epsilon}}\left[\frac{1 - rf + r^2 f^2}{f^2(1 - r + r^2)}\right]^{1/2m} \Delta t \tag{13}$$

and the increments of strain in the thinned section can be obtained using the Levy-Mises equations as

$$\Delta\epsilon_{\theta g} = \Delta\bar{\epsilon}_g\,\frac{(1 - rf/2)}{(1 - rf + r^2 f^2)^{1/2}} \tag{14a}$$

$$\Delta\epsilon_{rg} = \Delta\bar{\epsilon}_g\,\frac{(-rf/2 - 1/2)}{(1 - rf + r^2 f^2)^{1/2}} \tag{14b}$$

$$\Delta\epsilon_{zg} = \Delta\bar{\epsilon}_g\,\frac{(rf - 1/2)}{(1 - rf + r^2 f^2)^{1/2}} \tag{14c}$$

The increments of strain in the surrounding material are simply $\Delta\epsilon_z = \dot{\epsilon}_z \Delta t$ etc.

If the initial thicknesses in the thinned section and surrounding material are t_g and t respectively, then after a time interval Δt they will be

$$t_g(1+\Delta\epsilon_{zg}) \quad \text{and} \quad t(1+\Delta\epsilon_z) \quad \text{for the R-model}$$

and

$$t_g(1+\Delta\epsilon_{rg}) \quad \text{and} \quad t(1+\Delta\epsilon_r) \quad \text{for the Z-model}$$

Hence the change in f is given by

$$\Delta f \simeq f(\Delta\epsilon_{zg}-\Delta\epsilon_z) \quad \text{for the R-model}$$

and

$$\Delta f \simeq f(\Delta\epsilon_{rg}-\Delta\epsilon_r) \quad \text{for the Z-model} \tag{15}$$

NUMERICAL PROCEDURE

1. Choose value of $\dot{\epsilon}_\theta$, k and strain-rate exponent, m.
2. Set initial value of f and time interval Δt.
3. Calculate $\dot{\bar{\epsilon}}$ from Equation (4) and r from Equation (6).
4. Calculate $\dot{\bar{\epsilon}}_g$ from Equation (12) and $\Delta\bar{\epsilon}_g$ from Equation (13).
5. Calculate $\Delta\epsilon_{rg}$ or $\Delta\epsilon_{zg}$ from Equation (14) and $\Delta\epsilon_r$ or $\Delta\epsilon_z$ from $\Delta\epsilon = \dot{\epsilon}\Delta t$.
6. Calculate Δf from Equation (15) and hence new f.
7. Repeat 4 through 6 until f = 0.
8. Knowing total time and $\dot{\epsilon}_\theta$ and $\dot{\epsilon}_z$, calculate ϵ_θ and ϵ_z.

Thus for a given material, strain rate and strain-rate ratio, it is possible to find the compressive and tensile strains at fracture. By varying the strain-rate ratio, it is possible to construct a plot of tensile strain (ϵ_θ) versus compressive strain (ϵ_z) to fracture.

RESULTS AND DISCUSSION

Figure 3 shows a plot of tensile strain versus compressive strain to fracture for both the R and Z model using a strain rate of 10^{-4} s^{-1}, a strain-rate sensitivity exponent of 0.3, an initial damage factor, f, of 0.99 and a time increment of 100s. The shapes of the curves are very similar to those given by Lee and Kuhn for conventional cold forming, although, as expected for a rate-sensitive material, the strains to fracture are an order of magnitude larger. This shape similarity might be expected since the analyses follow quite closely. The difference in fracture strains occurs because in the original model the flow stress changes in both the thinned section and the surrounding material, while in the rate-sensitive model, since the strain rate is constant in the surrounding material, this flow stress does not change and only the flow stress in the thinned section increases. Thus there is a greater resistance to instability.

The strain rate used in the calculations has no effect on the fracture strains. This is reasonable since any change in practice is usually associated with strain-hardening effects or varying strain-rate sensitivity. If $\dot{\epsilon}_\theta$ is replaced in the analysis by $\Delta\epsilon_\theta/\Delta t$ it is clear that the change in f is a function of $\Delta\epsilon_\theta$ rather than $\dot{\epsilon}_\theta$ and that $\Delta\epsilon_\theta$ can be considered as the step size. Hence the step size is really not Δt but $\Delta t \times \dot{\epsilon}_\theta$.

The step size used in the calculations was 10^{-2}. Reducing this value was found to lower the curves insignificantly, but higher step sizes raised the curves a noticeable amount. Thus this increment is considered to give sufficiently accurate results.

The damage factor has some effect as shown in Figure 4, especially as it approaches unity. This was noted briefly by Lee and Kuhn in their work and presents one of the difficulties in using the model since it is difficult to determine f experimentally. The value used in the remaining results is 0.99 since both Lee and Kuhn and Marciniak and Kuczynski found that this value gave good agreement with their experimental results.

The Z-model provides the limiting condition for fracture for k values below 0.5, i.e. the thinned section of the Z-model thins more rapidly than the R-model for these k values. The R-model is the limiting case for $k > 0.5$. The overall fracture strain locus approximates a straight line of slope one half. Again this follows the model for conventional forging.

Figure 5 shows the fracture strain loci for different strain-rate sensitivity exponents. As expected the strains to fracture increase with increasing strain-rate sensitivity.

The fracture loci predicted from this model of localized thinning appear to be quite reasonable. Their shape is as might be expected and the order of magnitude of the fracture strains is correct. Use of the method is limited, however, by lack of experimental data. Most of the previous work on rate-sensitive forming has been concerned with either uniaxial tensile tests or sheet forming, and interest in the latter area has been focussed on the forming pressures. Very little work has been published on fracture strains except for uniaxial tension. However, with the increasing use of isothermal forging in the aerospace industry it will become increasingly important to be able to predict whether a forging blank will fracture during pressing. Clearly the present model is inadequate for a complete analysis of a complex forging, but it may be possible to apply the results to certain critical areas as suggested by Downey and Kuhn (Ref. 8) for powder preform forging.

The main limitations of the model are the requirement for constant strain-rate ratio and the assumption of a constant strain-rate sensitivity index. This could be overcome by a more complex analysis but it would not produce a general forming limit and the calculations would probably have to be carried out for every individual case. If experiments showed that the errors introduced by such assumptions were not large, then the forming limit presented could be of great value.

CONCLUSIONS

Theoretical forming limits have been calculated for rate-sensitive forging using a model of localized thinning. Although no experimental evidence exists to verify the model, the results follow what would be expected and the fracture strains are of the correct order of magnitude. The forming limit concept could be of use in isothermal forging if borne out by experimental results.

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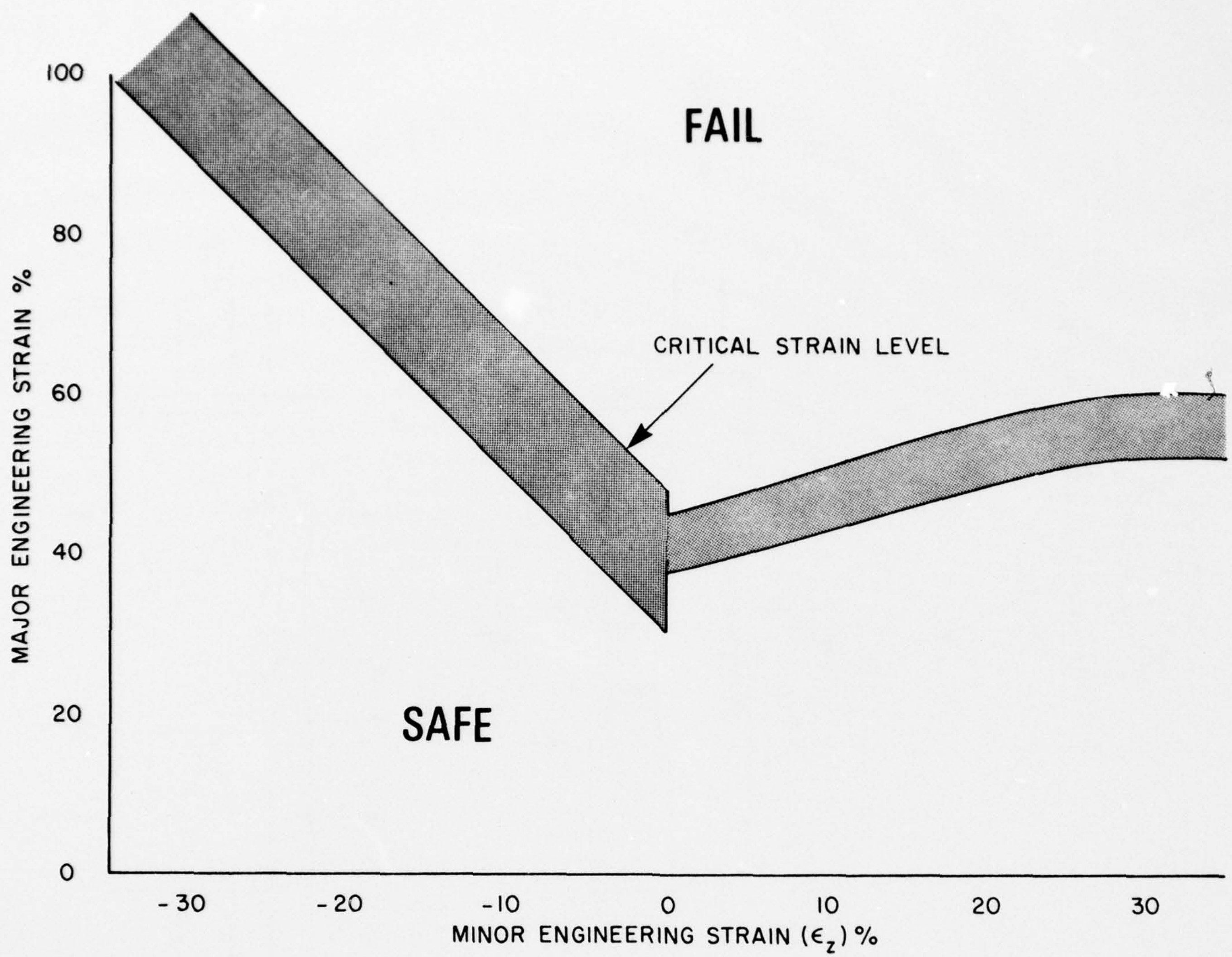

FIG. 1: TYPICAL FORMING LIMIT DIAGRAM FOR SHEET METAL

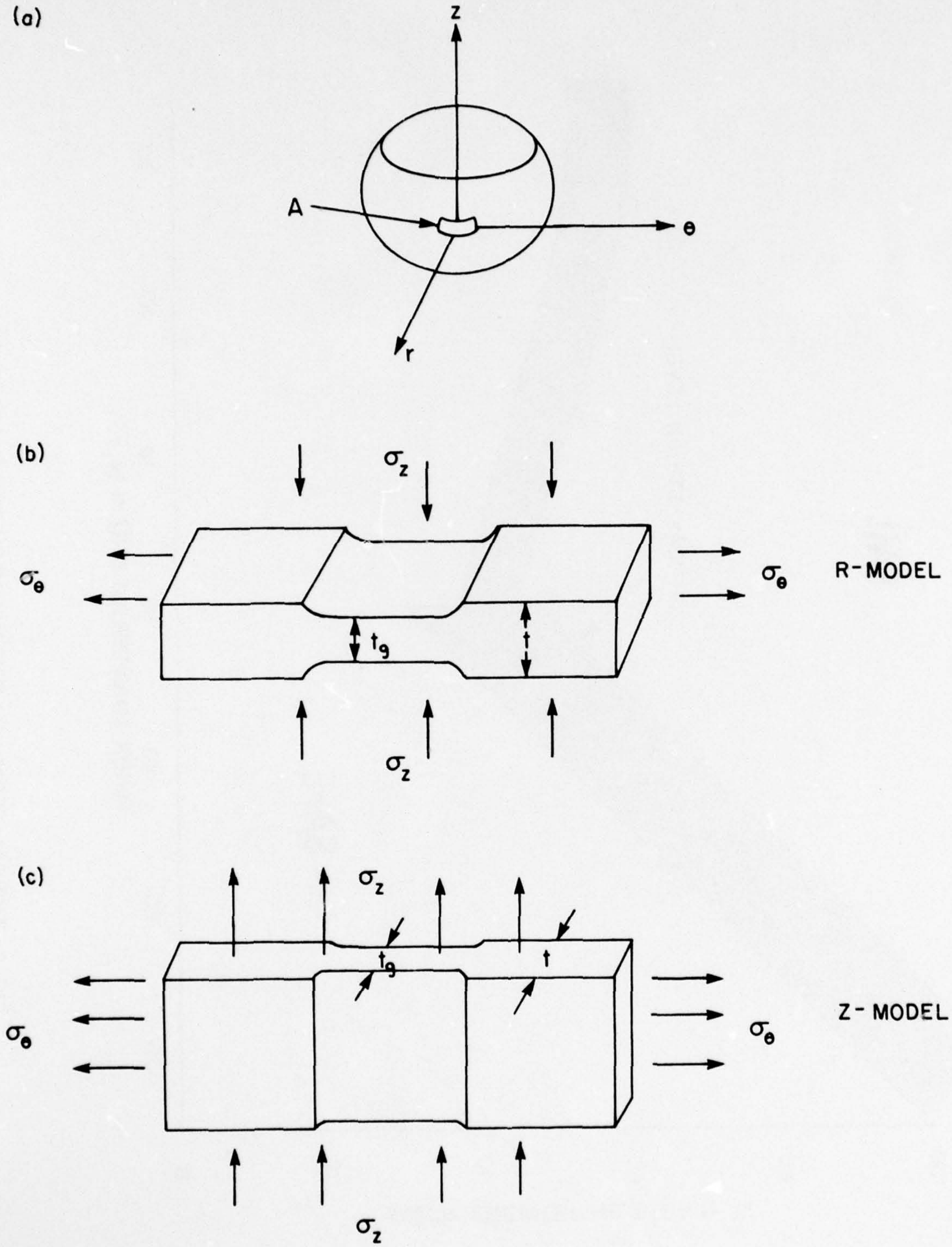

FIG. 2: MODEL ELEMENTS

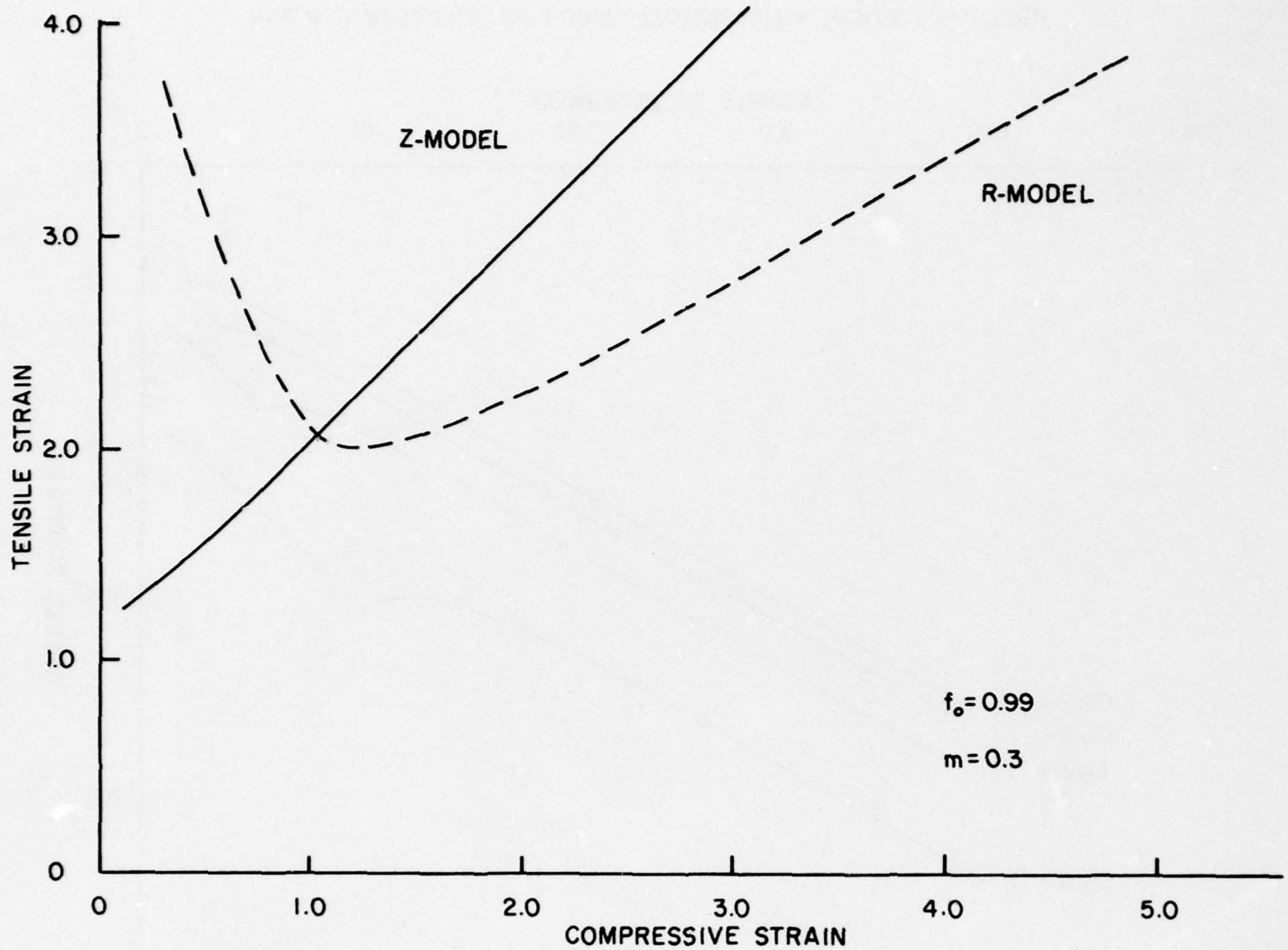

FIG. 3: LOCUS OF LIMIT STRAINS FOR R AND Z MODELS

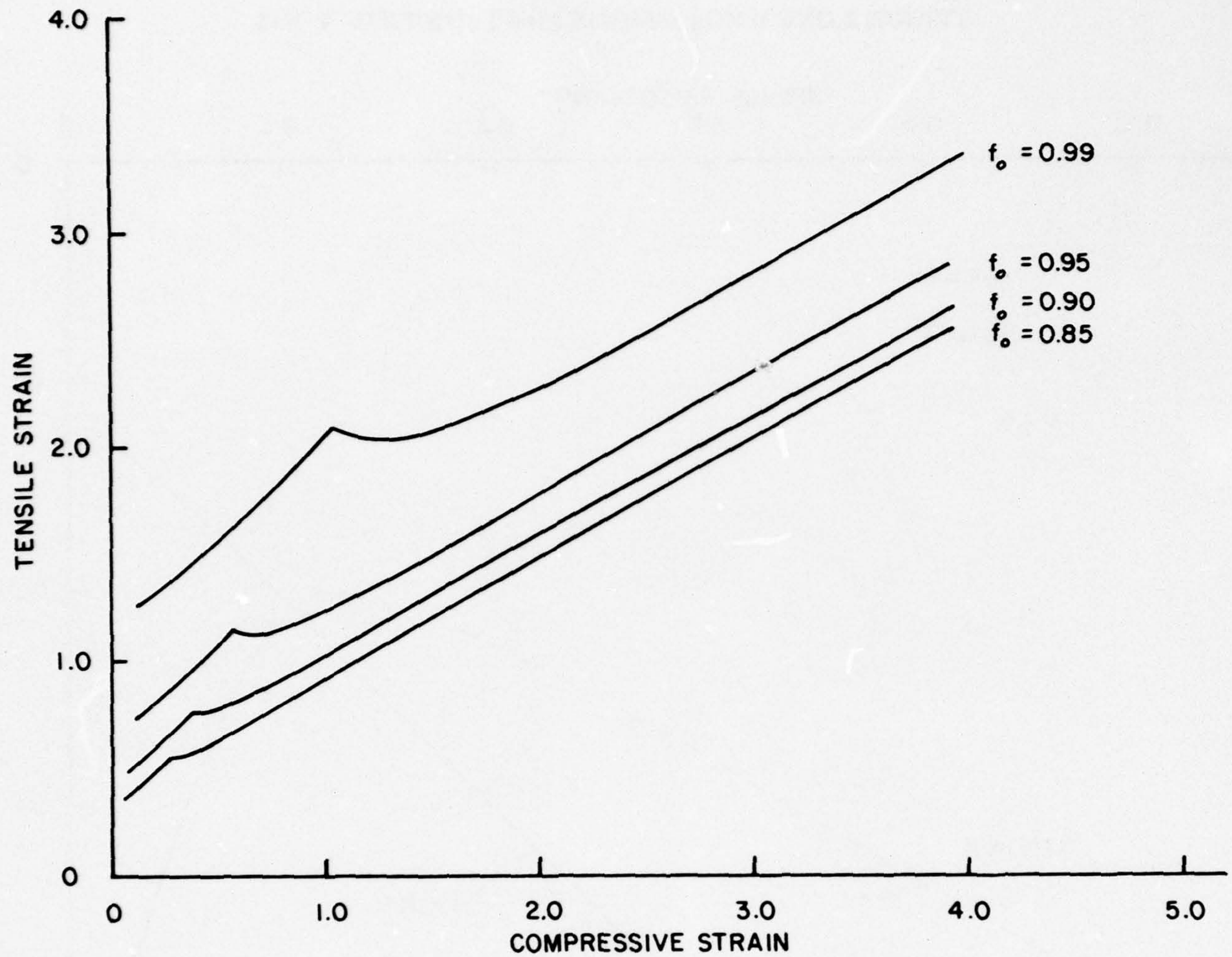

FIG. 4: VARIATION OF LIMIT STRAINS WITH DAMAGE FACTOR

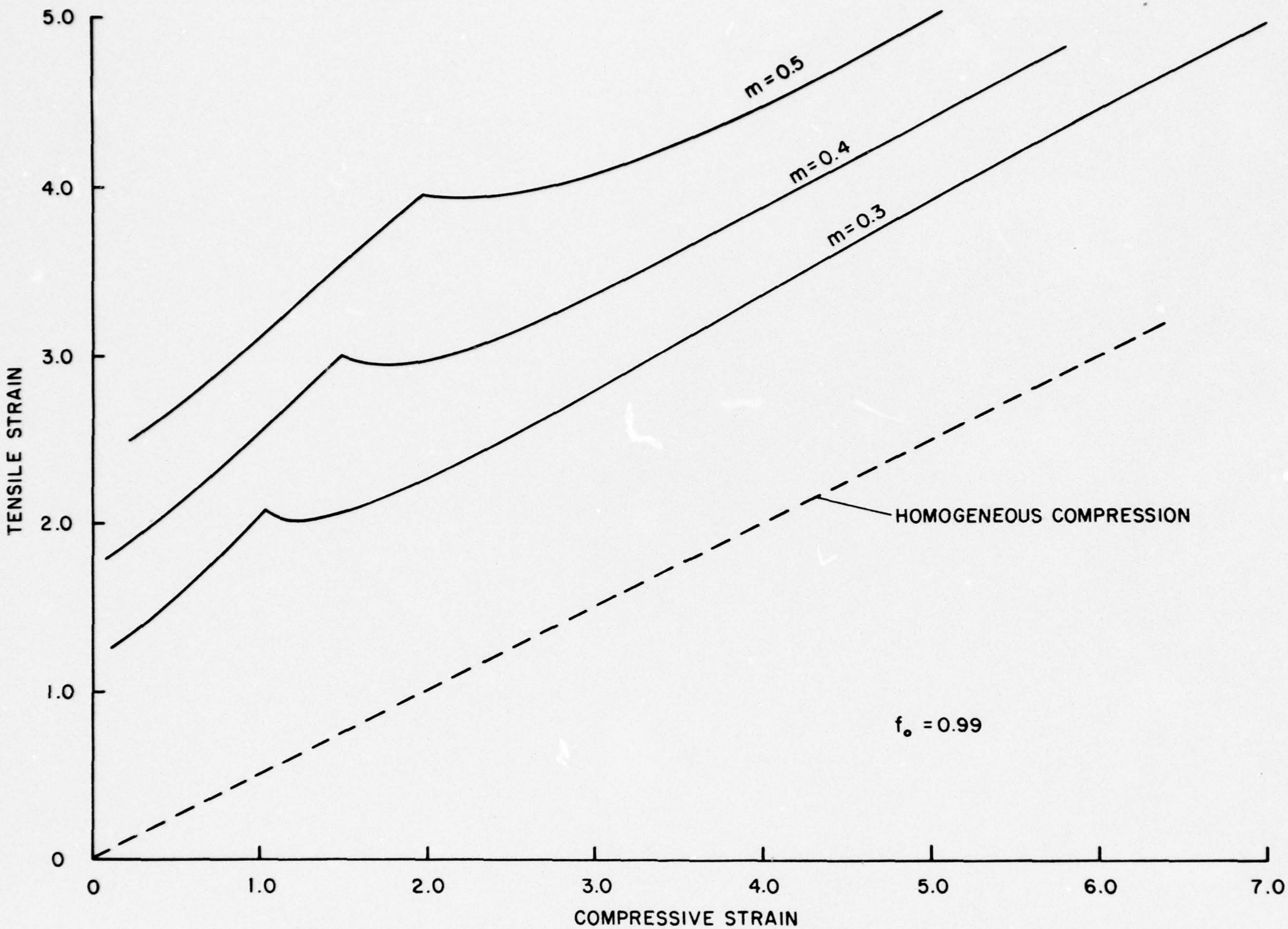

FIG. 5: VARIATION OF LIMIT STRAINS WITH STRAIN-RATE SENSITIVITY

TRENDS IN INDUSTRIAL CONTROL — A μP IN EVERY POD[†]

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ABSTRACT

There are many factors influencing future trends in industrial control systems. The control systems of tomorrow will reflect not only the changing needs of industry but also the many technological and engineering developments taking place in other areas. The most significant impact will be related, directly or indirectly, to microprocessors without which many technically valid approaches would remain economically unattractive. This paper examines some of these developments which are shaping the future of industrial control and identifies several problem areas which require further attention.

INTRODUCTION

Computer technology is advancing at such a pace and on so many fronts that it is difficult to keep abreast of the changing ground rules. At the same time industry is facing shifts in the economic climate with increased emphasis in such areas as energy management, pollution control, and conservation of natural resources.

Future industrial process control systems must reflect these changing demands by offering better control, reduced production costs, and more complete and accurate operating data upon which to base management decisions. The improvements in performance will be achieved by exploiting the new developments in computer technology.

New approaches create new problems. Solutions will need to be found before some of the emerging techniques can be regarded as viable alternatives. There is a need for standardization to provide a sense of direction and common purpose to future developments.

RECENT ADVANCES

The most significant advances in the computer field are those in LSI semiconductor technology. Steady improvement in production of LSI modules and fabrication techniques affords the following benefits: reduced cost per logic function, or memory bit, with an accompanying decrease in physical size; increased complexity, with implied enhancement of capability and performance; improved reliability. The new areas of application which have become accessible to the computer industry with the advent of the inexpensive yet powerful microprocessor are discussed later. There have been important developments in other areas as well.

The importance of man-machine communication is receiving increased recognition. Both black and white and colour T/V displays are being widely used. New terminals incorporating touch sensitive panels and plasma displays are available. Voice data entry for industrial applications is now a reality; a unit has been announced which is a direct replacement for a standard keyboard computer terminal.

Many lower cost peripherals such as cassettes, floppy disks, and fast serial printers which are more in harmony with minicomputer and microcomputer systems have been developed.

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† Presented at ISA/77 Niagara Falls, October 19, 1977.

Fibre optic cables are available at prices which are already competitive with coaxial cables having comparable performance. In time it is expected that prices as low as 10 c/m will be possible since the material costs are significantly less than this. Although as yet no simple method has been developed for tapping optical energy from fibre optic cables, they are currently being used in applications where the dramatic reduction in weight and volume, elimination of electromagnetic pulse effects, reduction in cross talk, wide bandwidth and electrical isolation are of paramount importance. As increased production and improved fabrication techniques make them more economically attractive fibre optic cables will have a significant impact on computer system design.

THE IMPACT OF THE MICROPROCESSOR

Users and vendors now have available inexpensive pre-packaged digital computing, with a high degree of modularity, and with well defined interface and control characteristics, as standard 'off-the-shell' components. Because of the modularity and low cost of microprocessors, "intelligence" will be added to practically every type of control and data entry equipment. Typical examples are:

- I/O device controllers
- terminal and graphics subsystems
- word processing systems
- automatic measurement and evaluation systems
- industrial process control

DISTRIBUTED INTELLIGENCE

As more processing power is distributed among special-purpose dedicated devices the trend in computer system design will be reversed. Systems with a single centralized intelligence source will be replaced by systems with distributed processing elements in which the computer is just a subsystem or component of the system. The intelligent subsystems then become components of a network in which microprocessors can perform the communications functions such as controlling the common bus, and packing and unpacking control information.

Future systems will become modular and expandable. As more power or new features are required new units will be added to the network in building-block fashion. Failure in a single subsystem will result in loss of that function but need not cause a total system failure. There may still be a central computer programmed for 'strategic' decisions but the microprocessors distributed within the system will be programmed for 'tactical' decisions.

In distributed intelligence systems the system *functions* are dispersed among special-purpose processors to make each functional level of operation more manageable to design and operate, to improve reliability, and to improve system response.

MULTIPROCESSOR SYSTEMS

The concept of distributed intelligence addresses the problem of concurrent processing within I/O subsystems and peripheral devices. Another emerging technique, greatly influenced by the advent of microprocessors, is multiprocessing. Multiprocessing systems deal with distributing a *task* or series of tasks over several processors, each capable of performing the task assignment. This allocation of tasks is associated with increasing processing speed.

Distributed processing systems are typified by dedicated special-purpose elements loosely coupled in a network. Multiprocessor systems are usually composed of a number of identical processors, often tightly coupled through a common shared memory.

The distributed-function concept is often associated with widely dispersed remote subsystems, but is equally appropriate for local I/O and internal CPU architectures. Similarly, multiprocessing is often described in terms of parallel operation of individual processing elements within a central processor but can be applied to networks of processors separated by large distances.

Multiprocessing is particularly attractive for improving microprocessor performance because currently processor speeds are five times slower than memory. Parallelism is an effective method of improving memory bandwidth utilization.

Just as microprocessors are being implemented in computer systems to improve performance and cost effectiveness, techniques such as pipelining (overlap) and microprogramming, borrowed from larger and more powerful computers, are being applied to microprocessors to enhance their performance.

TRENDS IN SOFTWARE

The problems faced by the designer of these new systems cannot be solved by pure reduction of components cost or of computing speed. The greatest payoffs will be derived by combining the advances in technology with the evolution of operating system design. Also, by placing some of the critical software functions in hardware, a greater degree of confidence can be obtained since these functions can be independently tested. This hardware support is not limited to the central processor components.

The availability of low-cost LSI hardware and the gaining need for improved reliability and maintainability have renewed interest in use of fault tolerant techniques. Fault tolerant design uses built-in redundancy in the form of repeated calculations, added software, or extra hardware to achieve reliable operation despite the presence of system component failures. One current trend in fault detection and diagnosis is increased use of error-detection and error-correction codes.

THE IMPACT OF THESE TRENDS ON PROCESS CONTROL SYSTEMS

The previous sections describe some of the recent advances and current trends in the computer field. Before examining the future of industrial computer systems with respect to these activities it is useful to review the evolution of process control.

Originally, process control systems were manual, with instruments, controllers, and actuators mounted directly on the production units distributed throughout the plant. Communication was a problem: the plant operator had to walk around the plant to gather measurement and other control data.

Automated process control made it possible to centralize operations, by gathering measurement information and distributing control commands. With one centralized data base, every loop effectively had access to the data associated with every other loop.

Until now digital processing remained centralized, sharing a single digital computer among many diverse tasks. Because of the reliability and security problems in direct digital control, distributed analog control (of each loop) remains in wide use — in spite of the fact that digital control offers many advantages.

Today, microprocessors enable distributed digital processing with all the advantages of centralized data manipulation, but with return of the control functions to the remote points where they can be most conveniently performed and managed, and at the same time avoid the risks of depending on a single computer.

COMPUTER CONTROL

The functions within an industrial plant which can be performed by a digital computer includes:

monitoring of sensors (both analog and digital)
calibration and conversion to engineering units
alarm scanning and checking

data logging
control
optimization
data processing and preparation of management information.

The use of a computer to perform any or all of these functions must be justified in terms of reduced production costs and increased profits. The advantages offered by computer control are:

fast response to both normal changes and emergency conditions

consistency of operation and the ability to maintain production levels at a maximum limit

possibility for total control from raw material to packaging and shipment of product

accurate and more complex operating data and collation of related events

continuous, reliable surveillance of selected conditions

peripheral equipment control, e.g. logsheet formatting and operation of sophisticated displays.

Use of a single central computer for process control poses some severe problems. The most serious is that a failure in this central control may result in complete loss of the plant operation. A single central processor capable of handling the multiple interleaved real-time timing and control commands must be a large, expensive installation with complex software. This implies problems in maintenance and fault diagnosis of both hardware and software. Further, a central computer can reach a point where it is fully loaded, especially when it is required to perform a large number of high speed repetitive operations. Further expansion of the system then becomes extremely difficult and costly.

These problems and the emergence of intelligent microprocessor-based instruments and actuators recommend a distributed architecture, as described previously, where the control functions are distributed among several special-purpose subsystems.

DISTRIBUTED CONTROL

Unburdening the central computer by distributing the control functions among several processing elements reduces the hardware and software complexity at each processor and avoids dependence on a single computer.

Reliability is increased, not only by removing the dependence of the process on a single computer, but also since there can be a high functional reliability of each of the special-purpose subsystems. These units can check the integrity of communications and verify data before taking action.

Each subsystem can be capable of running diagnostic tests on itself while in operation. Trouble-shooting is also simplified because the distribution by function minimizes the interference between subsystems. A malfunction is easily localized to the processor which performs the function which has failed. Serviceability is inherent since local units can be removed from the system without disrupting the plant.

Economies in hardware and software are achieved through reduced system complexity, increased standardization, and interchangeability of process elements.

Start up can proceed in a more orderly fashion because separation of functions makes it possible to actuate processors one at a time.

Modifications to an existing installation are more easily made and debugged because fewer software modules in each processor implies fewer unforeseen interactions between existing modules and new ones. The system can be easily expanded as increasing demands are made on it.

Systems can be built starting with stand-alone units and integrating upward by adding communication capabilities, or starting with centralized control and unburdening downwards through additional of more highly dedicated control devices. Lateral growth is possible by increasing the amount of processing power at diverse points.

Hardware and software redundancy are viable economic reliability techniques. Any of the data links could be implemented with two or more redundant channels.

The system can be designed so that a failure in one part of the network will not incapacitate the whole system but rather continue at some degraded level of efficiency.

System performance and response are improved by separating process responsibilities and enabling concurrent processing to occur.

Communications among the plant computers would not only provide a total picture of corporate production but would also facilitate transferring raw materials and finished product, smoothing loads and demands, and compensating for unexpected bottlenecks and shutdowns. Network communications provide a way of overlaying management upon control with neither the costs or the risks of the centralized approach.

ARCHITECTURE

The structure of a distributed control system can be arranged in numerous ways, the topology can be geared to the particular job. As well as supporting communication between subsystems and a central computer, it is also possible to provide the ability for local units to communicate with one another without any direct intervention from a central processor.

Direct communication between subsystems can increase reliability. If errors or failures are detected, units can select alternative commands, sources, or transmission paths. If the central computer fails the subsystems can continue operating with some co-ordination and synchronization of activities if they have the ability to exchange information.

COMMUNICATION SUBSYSTEM

Any network of interconnected processors may be conveniently partitioned into two separate subsystems: the communication subsystem which comprises the hardware and software necessary to interface the processing elements to common data channels and perform the exchange of information between them, and the collection of processing elements and terminals which form the processing subsystem.

Ideally the communication subsystem and the network functions which it performs should be invisible to system designers and operators, in the same sense that the internal structure of a single computer is not apparent to those who use it.

There are many features which must be supported by the communication subsystem in an industrial distributed control system. For example, volatile memory will be required in remote processors to accommodate modifiable data (as sensors age so will the compensation and calibration parameters, as processes change so will the alarm limits) so it must be possible to "downline" load this information from a central computer.

Many other design parameters, such as the type of bus structure (e.g. dedicated bus versus line sharing scheme), choice of message structure and protocol, are not so clearly defined by the application requirements. In the absence of other guidelines or constraints in these areas various vendors will make different engineering decisions and industry could be faced with a proliferation of distributed control systems with incompatible communication subsystems.

To the user such an eventuality would be most unattractive; his source of supply for new processing elements to expand his system would be limited to vendors offering compatible equipment.

Manufacturers often have mixed feelings about the desirability of standards. On the one hand, it immediately enhances the value of their products in that they can claim "compatible with Standard XXX". On the other hand, they wish to retain freedom to use their technical skill and experience to gain a proprietary advantage.

Standardization of the communication subsystem would ensure the level of compatibility which is desirable to users but would leave the design and implementation of the processing subsystem and its component processing elements in the hands of the vendors.

COMMUNICATION SUBSYSTEM STANDARDIZATION

In October 1975 in Paris a new Working Group (WG), authorized by Sub-Committee 65A (SC65A) of the International Electrotechnical Commission (IEC) held its first meeting. The scope of this Working Group, IEC/SC65A/WG6, entitled "Industrial process computer inter-subsystem communications" is in part:

> "To draft standards for inter-subsystem communications involving line-sharing within computer based systems for industrial process measurement and control."

The same month a new ISA committee SP72 "Industrial Computer Interfaces and Data Transmission Techniques" was established to act, in part, as the U.S. Advisory Group for IEC/SC65A/WG6. The committee is, essentially, the American Regional Interfaces and Data Transmission Committee of the International Purdue Workshop on Industrial Computer Systems (IPW).

Both groups, ISA SP72 and IEC/SC65A/WG6, have been developing a document entitled "Functional Requirements for Industrial Process Computer Inter-subsystem Communications" against which existing and proposed implementations can be evaluated.

In April 1977 the ISA SP72 document was accepted as an IPW document so that it could be made widely available. During the evaluation process it is expected that these functional requirements may be further refined, nevertheless the publication of this preliminary version should provide a useful guide to vendors as to the general direction and scope of the subsequent standard.

FUNCTIONAL REQUIREMENTS FOR INTER-SUBSYSTEM COMMUNICATION

This section contains excerpts from the ISA SP72 document described above. The complete document is freely available; the intention of the following is merely to convey some idea of the current status of this work.

"This paper describes the functional requirements for information interchange among subsystems of a computer based process measurement and control system. Each communication link of this type should be optimized to carry digital data using bit serial techniques over a single shared communication link. A complete industrial process computer *system* may contain several independent communication links forming a network. Acceptable communication proposals may also include versions using additional transmission methods, such as byte serial."

"The communications subsystem is to be used primarily but not exclusively in the process industries (for their continuous and their discrete processes). . ."

"It is not intended to provide an optimized interface for high-speed standard computer peripherals, such as mass memories, line printers, unit record equipment or graphical terminals. Nor is it intended for efficient sharing of mass storage or peripherals between processors."

"The communication subsystem shall be capable of supporting centralized intelligence, distributed intelligence, hierarchical intelligence and combinations thereof. In particular, it shall be capable of supporting distributed systems for process measurement and control.

The available architectures of the communications subsystems should not preclude direct data interchange between any two subsystems: it should be possible to transmit data directly between any two subsystems on the link without necessarily involving store and forward at a third subsystem.

The communication subsystem shall provide flexibility for the user to economically change or expand the process control system after installation within practicable address areas and distance limitations.

The communication subsystem shall include optional versions in which the transmission line can be extended or subsystems added. . . ."

"There are five levels of Protocol which may be used to functionally characterize the complete communications system used throughout a process control installation. These levels are:

Physical link protocol.
Communication link protocol.
Logical connection protocol.
Network control protocol (only required if more than one independent communication subsystem is covered by the complete process application).
Application protocol.

The allocation of specific functional requirements into these layers of protocol . . . is not intended to imply the structure of the communication system or the actual location of a function within the devices that implement the communication system."

". . . Network control and application functions are not included in the communication subsystem. They must be included for each particular application to make a complete working system."

"The communication system shall be capable of maintaining correct sequencing and integrity of transmitted data through an electrically noisy environment. . . ."

"Failure of any part of any subsystem attached to the communication subsystem shall not cause failure of the entire system or of any function except those in which the failed subsystem is directly involved.

It shall be possible to configure a system which will tolerate without loss of function the cutting of one point in the data channel. The system failure mode caused by any failure whose probability is statistically significant shall be non-catastrophic. A form of graceful degradation is required.

Availability of the communication subsystem itself should be high compared with the availability of the subsystems attached to it.

The flexibility of the communication subsystem shall support sufficient redundancy in centralized, distributed and hierarchical configurations to achieve high system availability. The communication subsystem shall have an internal status and error reporting capability, shall be capable of supporting self-recovery and shall permit loading, starting, stopping, reloading, and resetting a subsystem over the data channel."

SOFTWARE CONSIDERATIONS

The cost of software has been increasing at an alarming rate: the annual cost in the U.S. is estimated at 20 billion dollars. The new architectures and trends in computers described above are a response to the increasing software costs as well as to the decreasing hardware costs. It is economically attractive to simplify software components by increasing hardware complexity. For example, in distributed systems, the cost and complexity of communication is justified by the benefits achieved through relaxing the requirement of a high performance multi-tasking real-time operating system in the central computer. Already LSI receiver/transmitter chips are available which perform such functions as bit stuffing and stripping, frame character generation and detection, and error checking for bit oriented protocols. This trend toward the implementation in hardware/firmware of the software support in the communication subsystem applies also to many operating system features and other system software.

The use of high level programming languages has been the traditional answer to high software costs. FORTRAN is the most widely used language in industrial computer applications even though it has limitations when used in real-time applications. Further, the language was designed for single stand alone computer systems. ISA committee SP61 has developed extensions to FORTRAN for real-time applications, and is currently completing work on extensions for parallel processes. These extensions are acknowledged to be short term solutions. In response to the recognized weaknesses of FORTRAN a number of other languages have been developed for automation and control applications. Examples are PEARL, CORAL66, RTL, and PROCOL.

The High Order Languages Committee (HOL), of the U.S. Department of Defense has been heavily involved in the definition of requirements for a procedural language. Because of the similarity between defense requirements and those for industrial computer systems, this work is now being co-ordinated with similar activities within the International Purdue Workshop on Industrial Computer Systems.

In November 1976 a new working group of the International Standards Organization (ISO), ISO/TC96/SC5/WG1, entitled "Programming Languages for the Control of Industrial Processes" was established. The scope of this Working Group is:

> "Standardization of one or more high level computer programming languages and/or extensions to languages intended for general applicability in industrial real-time computer systems."

CONCLUSIONS

This survey has reviewed the recent advances and current trends in computer technology. The decreasing cost of hardware due to large scale integration and cheap microprocessors herald new approaches to both the internal architecture of computers and the structure of computer systems.

In particular, the trend in industrial computer systems is toward distributed control systems with microprocessors imbedded in special-purpose subsystems performing dedicated processing and network functions. Standardization of the communication subsystem will ensure compatibility between systems and will focus design efforts toward improvements in the processing subsystem.

The immediate challenge is in software development. The hardware technology is available, but the full potential of distributed control will not be realized without improvements in operating system design and standardization of a suitable high level language for industrial real-time applications.

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A MAJOR REFURBISHING PROGRAM FOR THE NAE 5-FT. X 5-FT. BLOWDOWN WIND TUNNEL

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PREAMBLE

During its fourteen years of service, with nearly 20,000 blowdowns, the NAE 5-ft. X 5-ft. wind tunnel has suffered a few major *blows* to its system, which have required fairly extensive repair jobs. For most such cases it has been possible to effect immediate repair, even to such a major component as the compressor plant — its 11,250 hp electric motor and the high speed epicyclic gear. The motor suffered a burnt-out rotor winding and the gear suffered fractured sun and planet wheels. These were instantaneous failures, occurring without warning. However, the response time of the parties involved in effecting a repair was commendably short, resulting in a minimum down time of the facility. Another case was the collapse of the exhaust silencer. In this case there was no question of repair, just the removal of debris.

Another type of failure, that turned out to become a rather regular event, has been the loss of turbulence damping screens in the settling chamber. These have failed at an average rate of one for every 5,000 runs, and of the original seven screens only three remain. When it became clear that a screen failure was to become a recurring event, plans were initiated for replacement of all seven screens. Also an investigation into the cause of the screen failures was undertaken. Some results of this investigation are discussed in Reference 1. Briefly, the flow entering the settling chamber was found to be wildly fluctuating, with peak dynamic pressures being an order of magnitude higher than that for uniform flow. Also, an examination of the edge fixation of the screens revealed some deficiencies in both design and manufacturing procedures, that resulted in stress concentration and promotion of fatigue failures, Reference 2.

It is the purpose of this article to give a brief account of the actions taken on screen replacement and on modifications aimed at significantly improving the settling chamber flow quality, thus hopefully preventing any future breakdown of screens, and also, as a consequence, improving the flow quality in the test section of the wind tunnel.

Furthermore, a Mach number control system and a new data acquisition system under development will be briefly described.

SCREEN REPLACEMENT

The most obvious way of arranging for a screen replacement was quickly ruled out, since the company that did the original job (in 1960) was no longer in existence and, furthermore, all of their relevant records had been destroyed. Attempts to interest other companies in such a special job also failed. Consequently, the only way out was to produce the screens as an in-house operation.

The original screen material is composed of 0.032-in. diameter stainless steel wire with 11 mesh per inch giving 43.6% porosity. Only one manufacturer with a large enough loom to weave the 18-ft. wide material, could be located on the North American continent. It rather fortuitously turned out that this company had been the supplier of the original material. An order was initially placed in March 1975 for a direct replacement of the seven original screens. This order was later changed to six 10 mesh screens and one 7½ mesh screen. The change from 11 to 10 mesh (43.6 to 46.2% porosity) was a concession to the manufacturer, the reason for the more open seventh, the most downstream, screen (57.8% porosity) was a belief that this would enhance the uniformity of the turbulence, as evidenced in Reference 3.

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The ordered screen material arrived in January 1976 but was unacceptable. Due to an unfortunate but understandable misunderstanding, the delivered weave was a plain weave, i.e. practically all the crimp (80%) was in the warp rather than an equal amount in the weft and warp. Simple stressing showed the plain weave to be completely unacceptable in our environment. A new batch of screens with a 50/50 crimp ratio was negotiated, at a considerable increase in cost. This second set of screen material was delivered in November 1976, and found acceptable.

It was decided at an early stage to use the same type of edge attachment for the new screens as for the old ones. Basically, the weave is wrapped around a steel cable with a thick layer of rubber vulcanized onto the edge to form an integral part of the screen and cable, Figure 1. Ninety spring supported clamps are then providing fixation for each screen over the vulcanized cable-screen edge. In the new set of screens, the diameter of the cable has been increased from ½ to 1 in. and the width of the clamps has been increased in order to improve the load distribution along the edge. A stress analysis performed indicated that in order to minimize stress concentration in the screen, it would be necessary to have the screens pretensioned so that the cable could not buckle under load. This was not possible with the original clamps and cable which were designed for a catenary type of edge fixing. A considerable amount of effort has gone into the design and manufacturing of tools for the bending of the weave around the cable and for the dies required for the edge moulds with the attached skirt-bellmouth (see Fig. 1).

MODIFICATIONS TO THE SETTLING CHAMBER INLET DIFFUSER

The basic geometry of this area is given in Figure 2. It was concluded from the measurements presented in Reference 1 that the flow approaching the first turbulence screen was of very poor quality with peak dynamic pressures being of an order of magnitude larger than that for a uniform flow. The flow distribution was also found to be a function of control valve position — this characteristic was reflected in the test section flow angularity, which also changed noticeably with control valve position (at about 50% of full stroke). It became clear that the wide angle inlet diffuser was never running full — the resistance, or pressure drop provided by the two perforated plates was obviously insufficient to make the diffuser flow full.

The original perforated plates have a verified porosity* of 52% and 54% respectively, the smaller plate with 2-3/8-in. holes at 3-in. spacing and the larger one with 1-7/16-in. holes at 1-13/16-in. spacing. The pressure drop under maximum mass flow conditions is estimated to be about 1.7 bars over the small plate and about one-seventh of this, or 0.25 bars, over the second plate. It is understood that the design philosophy that led to the choice of these porosities was based on low speed wind tunnel design data, the only one available at the time. However, it is quite clear from our analysis of the existing situation that the second perforated plate is far too open to serve a useful function. Before deciding which course of action to follow, we discussed our findings with the company involved in the original design of this wind tunnel, and it was suggested that the porosity of the second porous plate be reduced to about 23%, while maintaining the original porosity (assumed to be 44% in accordance with the drawing) for the No. 1 plate (Ref. 4). This would generate about equal estimated pressure drop (1.8 bars for maximum mass flow) across the two plates.

A design and stress analysis of a 23% perforated plate was then undertaken by B. Thorsteinson. It was shown that in order to operate at the same nominal stress level as for the existing, 54% porosity, plate (3/4 in. thick), which has required frequent weld repairs, a 23% porosity plate would need a thickness of 3 in. This was deemed too thick from a manufacturing and handling point of view. With the diffuser half angle being 30°, the natural radius of curvature for the porous plates is equal to the diameter of the plate. One way of decreasing the stress level is to reduce the radius of curvature. The possibility of halving the radius was considered; this would have reduced the plate thickness to a more manageable 1½ in., but was found incompatible with the existing attachment on the conical shell. As a structurally acceptable compromise it was decided to pursue a design with a radius of

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* Quoted porosities are based on plate open area divided by the spherical cap area extrapolated to the diffuser wall.

curvature reduced by 20% and a plate thickness of 1½ in. This would result in a higher nominal membrane stress than at present. However, this was deemed acceptable since strain-gauge measurements had shown that the dynamic stresses were the dominant ones and there were reasons to believe that these would be reduced with the anticipated improvement in the diffuser flow. A further consideration had to be given to the attachment of this much heavier loaded porous plate to the conical shell. Would, for instance, a reinforcement of the shell be needed? The results of an independent stress analysis (Ref. 5), coupled with strain-gauge measurements on the wind tunnel shell under various run conditions, provided the answer. The stresses in the shell, with the 23% porosity plate, would be within the limits set by the pressure vessel code. This is with allowance made for the required increase, over the existing ones, in the number of holes (from 90 to 180) and in hole diameter from 1 in. to 1.25 in. for the attachment bolts.

Two other items that also affect the flow into the settling chamber are the so-called cruciform with the conical centre-body and the control valve exit contour. The importance of the latter had been demonstrated beyond doubt for the existing situation, Reference 1. The need for the cruciform was questioned, conveniently so, since it was requiring frequent repairs, and records of earlier pilot tunnel studies about its significance were incomplete in many respects. Also, it was hoped that the much reduced porosity of the second perforated plate might render the cruciform redundant.

In order to establish the relative importance of the second plate porosity, the cruciform-cone and the control valve exit contour, a study was undertaken in the NAE 5-in. × 5-in. pilot wind tunnel, initially by D.J. Peake and S. Lockyear and later pursued by A.Bowker, S. Lockyear and the author. Only some qualitative comments about the results of this investigation will be provided here. Most comments are based on results of a pitot rake survey in the downstream part of the settling chamber for a mass flow equivalent to a stagnation pressure of 2.35 bars and a test section Mach number ~ 0.8. This corresponds to about half the maximum operating mass flow for the 5-ft. wind tunnel. The pressure measuring system had a frequency response of ~ 20Hz. It was established that:

1. with control valve and inlet cone geometry as for the existing 5-ft. × 5-ft. wind tunnel, the flow character in the pilot tunnel settling chamber was similar to that established for the 5-ft. wind tunnel, with one proviso, the No. 1 porous plate in the pilot tunnel had 41.2% porosity, not 52% as in the 5-ft. wind tunnel;

2. changing the porosity of the second perforated plate from 54% to 23% improved significantly the settling chamber flow distribution. However, a dependence on the control valve stroke would still be observed;

3. the cruciform-cone was essential for maintaining acceptable settling chamber flow, even with the low porosity second perforated plate. A wedge-shaped cruciform, Figure 3, structurally superior to the present flat plate cruciform (20 times stiffer) showed a slight aerodynamic advantage over its flat plate counterpart;

4. increasing the angle of the conical centre-body from the original 60° included angle to at least 75° had a marked beneficial effect on the mean flow distribution and on the fluctuating level. Increasing the cone angle beyond 75° up to 90° gave further improvement in the flow but produced unacceptably high static pressure differences across the No. 1 perforated plate;

5. simulating an increased angle of the conical centre-body by attaching a circular disc, with clean or serrated edge, to the base of the basic 60° cone, gave nearly the same improvement in flow as the equivalent cone;

6. the static pressure decrease across the perforated plates, as measured via four manifolded wall pressure ports upstream and downstream of each plate, showed peculiar characteristics. The decrease across the No. 1 plate was strongly dependent upon the geometry of the conical centre-body and showed also a dependence on the control valve stroke. For some cases a small pressure increase was measured for the first 50% of the control valve stroke. The pressure decrease across the No. 2 perforated plate (23% porosity) showed no such dependence on changes to the upstream geometry;

7. a buffer screen located at the trailing edge of the acoustic baffles improved the flow distribution and reduced the fluctuation level significantly. However, the same effect was obtained with an equivalent screen in the normal position for the first upstream settling chamber screen.

8. a first attempt to a m[illegible]ed control valve contour did not show any improvement in flow.

A qualitative picture of the improvement in settling chamber flow, that was obtained with these modifications, is given in Figure 4. These results are deduced from plots obtained with an x-y plotter on line. The indicated fluctuation levels must therefore be considered well attenuated because of the low frequency response of the plotter.

Based on these findings we decided to include the two new perforated plates, with 41% and 23% porosity respectively and a 75° conical centre-body in the rebuild of the wind tunnel, but to retain the present flat plate cruciform. The buffer screen concept, in spite of its merits, was dropped because of difficulties in arriving at a practical scheme that would not add unduly to the current inspection and maintenance procedures. An earlier argument for the buffer screen concept was that it would act as a buffer for the first screen, protecting it from the onslaught of the widly unsteady flow. The much improved flow obtained with the reduced porosity No. 2 perforated plate and the 75° conical center-body weakened this argument considerably. The possibility of a modified valve contour would be pursued with further studies in the pilot tunnel. A valve contour change, if proven beneficial, could be incorporated during a normal service period of the 5-ft. wind tunnel.

The modifications that are thus being incorporated create quite a change in the blockage pattern in the settling chamber and inlet diffuser, as seen in Figure 5. The figure shows the flow area distribution from the control valve up to the contraction. The solids represent the geometric area blockage due to the cruciform-cone, perforated plates, etc. before and after modifications. The control valve area is for the valve fully open. The most notable change is in the increased blockage by the second perforated plate. Less notable is the small blockage provided by the cruciform-cone and rather remarkable then, when seen in this light, is the crucial importance this part has on the quality of the settling chamber flow, as seen in Figure 4. One cannot but conclude that the inlet conditions to the wide angle diffuser is of paramount inportance for good settling chamber flow, even with high flow resistance in the diffuser (unless of course the second perforated plate is designed to run fully choked).

MACH NUMBER CONTROL SYSTEM

For subsonic operation up to $M \sim 0.97$ the test section free stream Mach number is controlled by the width of the diffuser second throat. For $M > 0.97$ the diffuser re-entry flaps (controlling the plenum chamber flow into the diffuser) provide the controlling function. Only the re-entry flap system can operate under wind-on conditions. An analysis of the diffuser second throat actuator system has shown that it is impractical to operate wind-on for Mach number control.

A requirement was drawn up for the design of a system that would set and hold the Mach number to within ±0.001 for $M < 0.97$ and to have an operating range of at least ±0.05 in M to be able to counteract model blockage effects. Also, the same system should be effective when operating the wind tunnel in its two-dimensional mode (the 15-in. × 60-in. insert). A translating choke system, positioned at the diffuser second throat, was considered as a favoured alternative.

A design based on the above requirements was completed (Ref. 6) and is being manufactured. The system consists of two vertically translating chokes protruding through the centre of the floor and ceiling respectively at the second throat, Figure 6. The chokes are 8 in. wide and have a total traverse of 30 in. Their translation is effected by a servo controlled hydraulic circuit responding to an error signal generated by the measurements of the stagnation and static (plenum) pressures.

The sensitivity of the system can be estimated from the known second throat area-test section Mach number relation, Figure 7, which close to M=1 differs significantly from the theoretical one-dimensional area-Mach number relation, particularly so for the two-dimensional case. This difference is essential for achieving good Mach number control close to Mach one. The sensitivity as represented by the slope of the lines in Figure 7 is shown in Figure 8. It is worth noting that the sensitivity, or gain, is only changing by a factor of three for the 3-D case, much less for the 2-D case, for the full Mach number range, while in theory the gain change would have been infinite over the same Mach number range. Thus the dynamic control of the system is expected to be fairly easy to handle. The operating range of the choke system is given in Figure 9, which points out an added feature above the original requirements. It will be possible to perform a Mach number sweep over a significant range — say from M=0.75 to 0.95. Also shown in the figure is the gain in terms of choke movement. One can deduce from this that in order to achieve ±0.001 accuracy in M at a nominal M=0.8 say, the choke position must be correct within ±0.180 in. and ±0.086 in. for 3-D and 2-D operation respectively — in either case, a very reasonable requirement.

DATA ACQUISITION SYSTEM

The present system has been in use since 1971. It has 20 low level (±5 mV) and 10 high level (±5 V) amplifier channels, an analogue-to-digital converter with a resolution of ±16000 counts with a sampling speed of 25,000 samples per second and a Honeywell DDP-516 computer with 16K word core memory capacity supplemented by a drum memory unit of 256K word capacity. Two magnetic tape units provided for the main data output on 9-track magnetic tape which is processed on NRC's IBM 360/67 computer. Although it was intended to develop the system to perform a limited amount of data reduction, not much was accomplished in that direction. In the past two years we have been made painfully aware of the vulnerability of this system, particularly with regard to service and spare parts for the main processor. A careful review of the status of the present system, its potential and the cost of maintaining it was carried out and supplemented by a market survey of replacement systems, Reference 7. In line with the conclusions of this study, it was decided in early 1976 to stop any further development of the present system and direct available efforts and resources into acquiring a completely new system with a target date of installation set for early 1978. To date, most of the components for this new system are in the laboratory being checked out and used for training of personnel. The new data system, Figure 10, will have 48 low level dual amplifier channels (expandable to 64). The new in-house built amplifiers have automatic read-out of gain and filter settings and provision for automatic calibration. The analogue-to-digital converter has the same resolution as the old system, ±16000 counts, but a considerably increased sampling speed of 100 kHz, thus allowing the system to be used for recording most transient and dynamic phenomena on all channels.

The heart of the system is the PDP 11/55 data processor with a 64K memory and two disc units with a total storage capacity of 2.4 million words. Two magnetic tape units, of considerably higher quality than the present ones, provide for the main data outputs as in the previous system. A display unit with hard copying facility will be used for quick look. As indicated in Figure 10, the possibility of remote terminal connection has been considered and is well within the capacity of the system.

The new system also encompasses a PDP 11/V03 peripheral processor, to be dedicated to certain control functions, such as Mach number, stagnation pressure and model attitude controls.

The potential of this system is such that with enough programming effort, on line (i.e. between runs) data reduction can be carried out. Initial efforts will be directed towards producing plots and listings of uncorrected reduced data.

CONCLUSION

In early July 1977 the NAE 5-ft. X 5-ft. wind tunnel was effectively shut down in preparation for this refurbishing program. The contract for the disassembly and reassembly of the settling chamber was awarded to a local company, which commenced its work in early August. The estimated time for

completion of the then known work was 16 weeks. On opening the settling chamber it was found that the acoustic baffles were in poor shape and in need of extensive repair, adding several weeks to this estimate. In fact, the reassembly of the wind tunnel was not completed until February 1978. The following major modifications have been incorporated:

1. a complete set of new settling chamber screens

   six 10 mesh, 0.032 in. ϕ wire, 46.2% porosity
   one 7½ mesh, 0.032 in. ϕ wire, 57.8% porosity;

2. two new perforated plates —

No. 1	1.19 in. thick	2.06 in. ϕ holes	41% porosity
No. 2	1.50 in. thick	1.25 in. ϕ holes	23% porosity

3. a 75° included angle conical center body on inlet cruciform;

4. preparatory work in the diffuser second throat area to accept Mach number control system;

5. installation of 30 new data amplifiers in preparation for the installation of the new data system.

A long neglected area of the wind tunnel has been the exhaust diffuser. For several years the diffuser has been running resistance free. The two screens in the wide angle diffuser had to be removed because of excessive fatigue fracturing of the 1-in. rod material making up the screens and the collapse of the silencer has already been mentioned. In the long run this is not considered to be a healthy situation and a study has been launched into a new screen design. The screens would be mandatory should a silencer eventually be required for environmental reasons.

ACKNOWLEDGEMENT

A special tribute to be paid for Mr. R.H. Piper for his tireless efforts that resulted in the successfull design and manufacture of the seven settling chamber screens.

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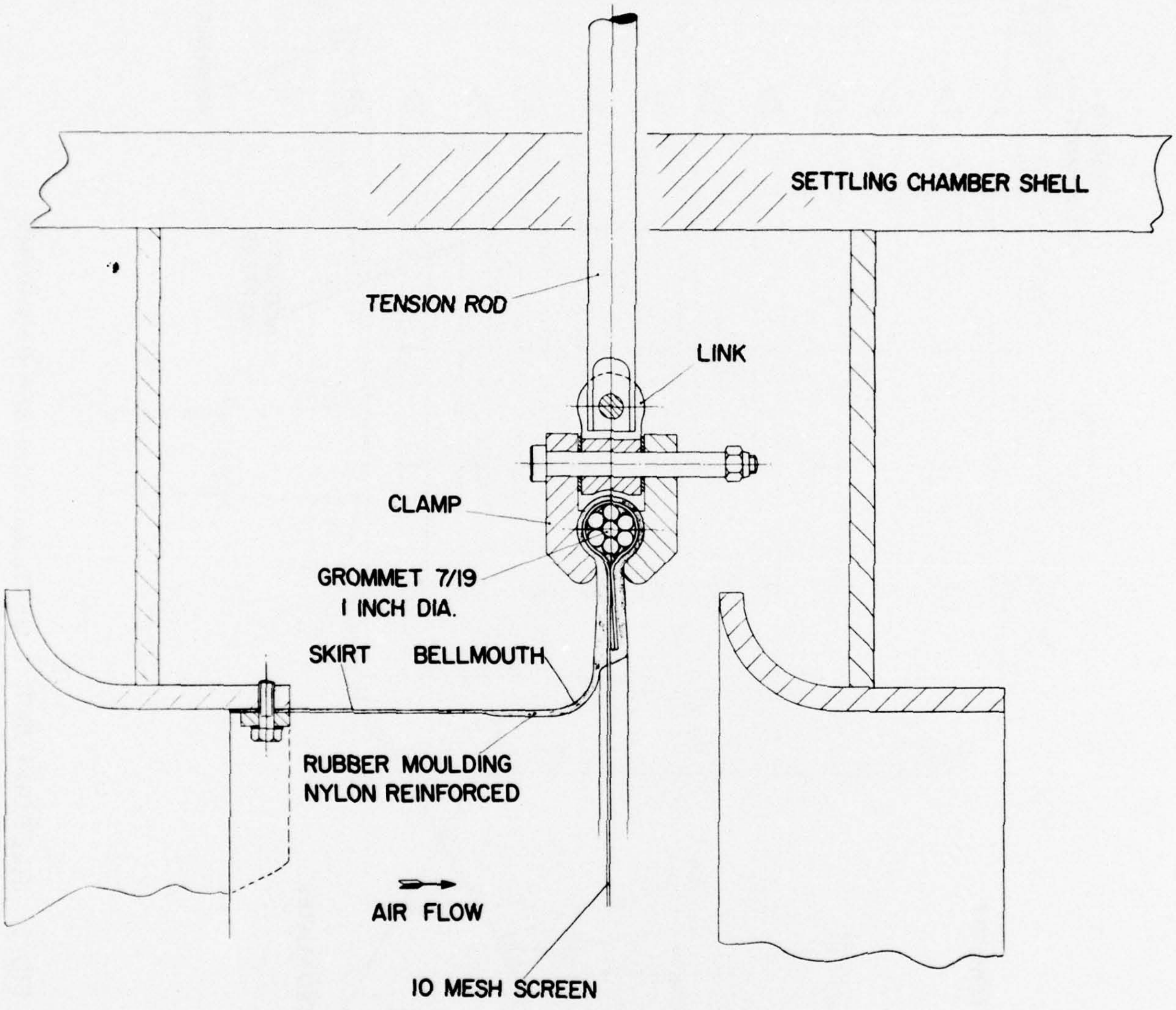

FIG. 1: SCREEN ATTACHMENT

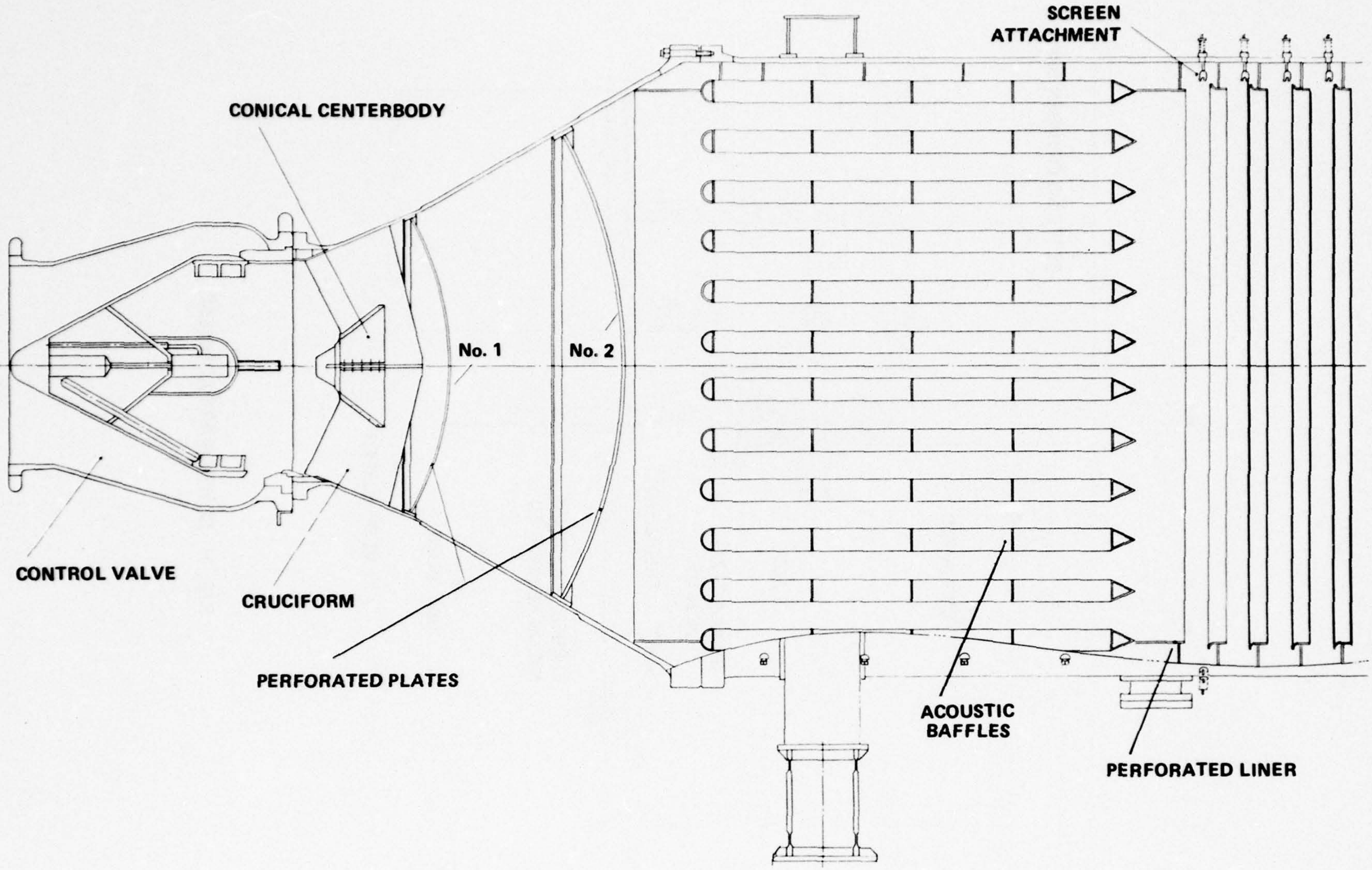

FIG. 2: INLET DIFFUSER – SETTLING CHAMBER GEOMETRY

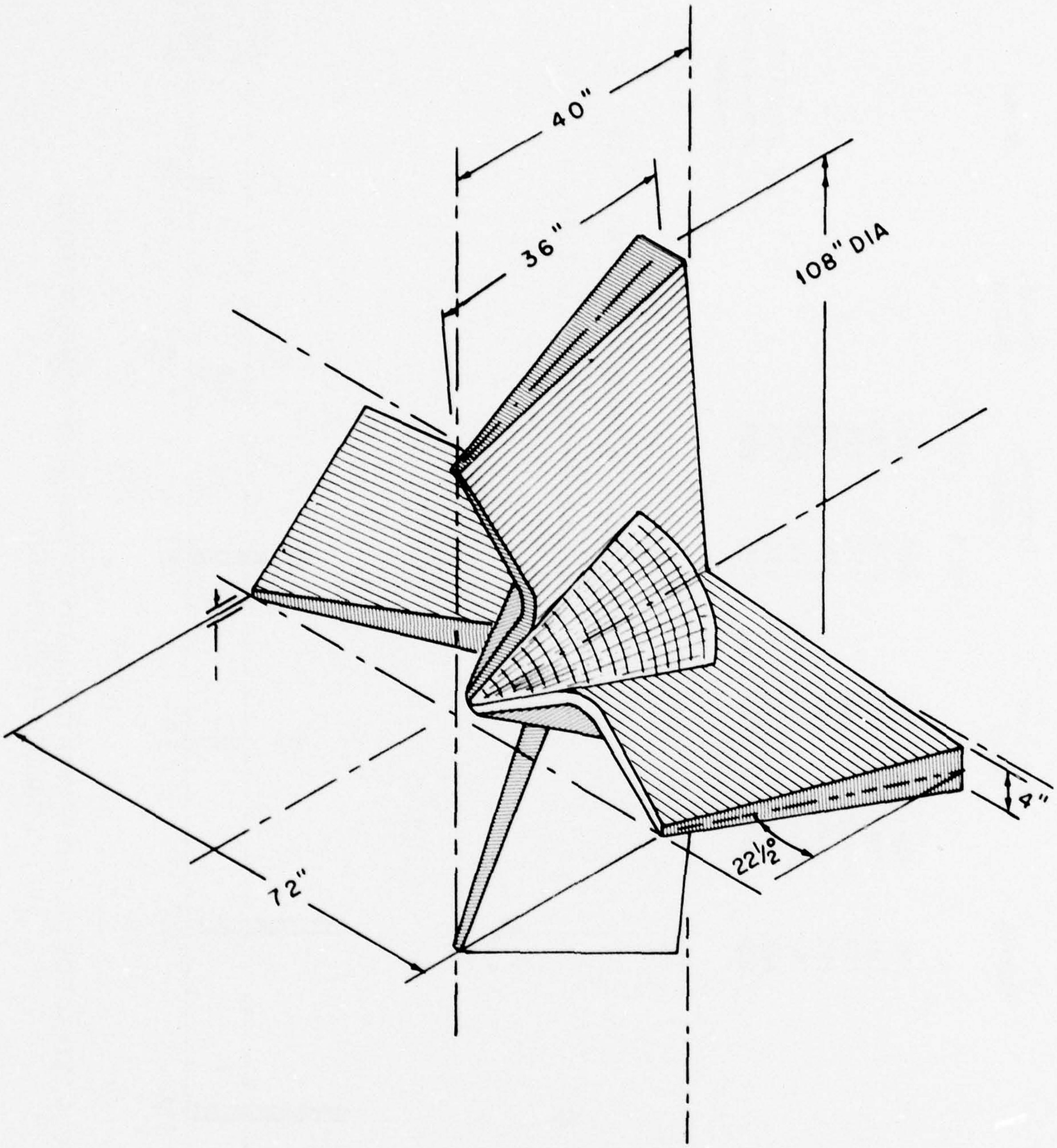

FIG. 3: WEDGE SHAPED CRUCIFORM IN 5-FT. × 5-FT. WIND TUNNEL SCALE

Run No.	Cruciform cone		Perforated plates No. 1	Perforated plates No. 2	Acoustic baffles	Screen
122	flat plate,	60°	41%	54%	√	–
136	flat plate,	60°	41%	23%	√	–
141	wedge	60°	41%	23%	√	–
138	wedge	75°	41%	23%	√	–
157	wedge	"70°" disc	41%	23%	√	–
158	wedge	"70°" disc	41%	23%	√	"2q" at baffle T.E.
159	wedge	"70°" disc	41%	23%	√	"2q" at No. 1 screen normal location

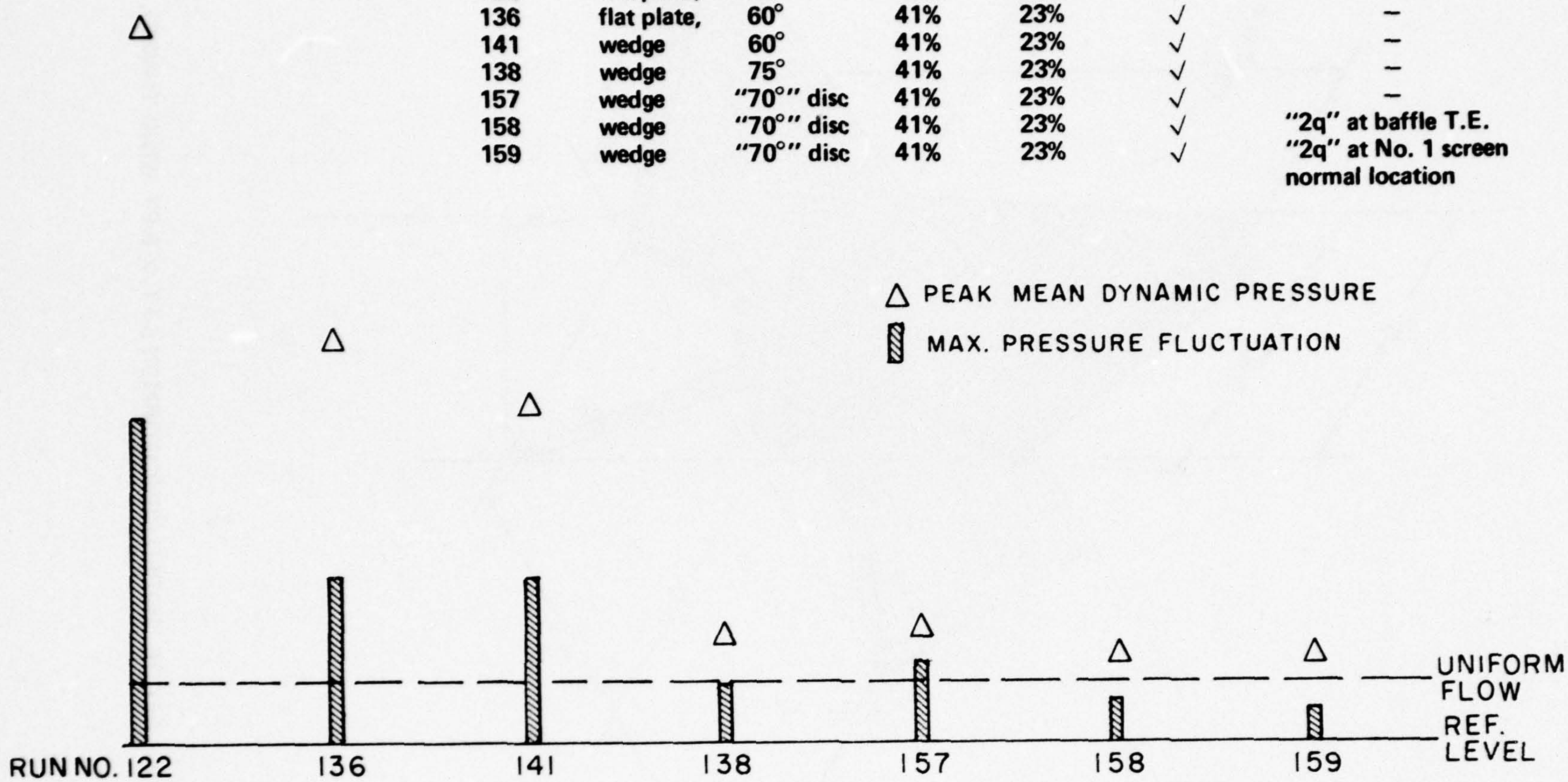

FIG. 4: EFFECT OF INLET DIFFUSER GEOMETRY ON 5-IN. WIND TUNNEL SETTLING CHAMBER FLOW QUALITY

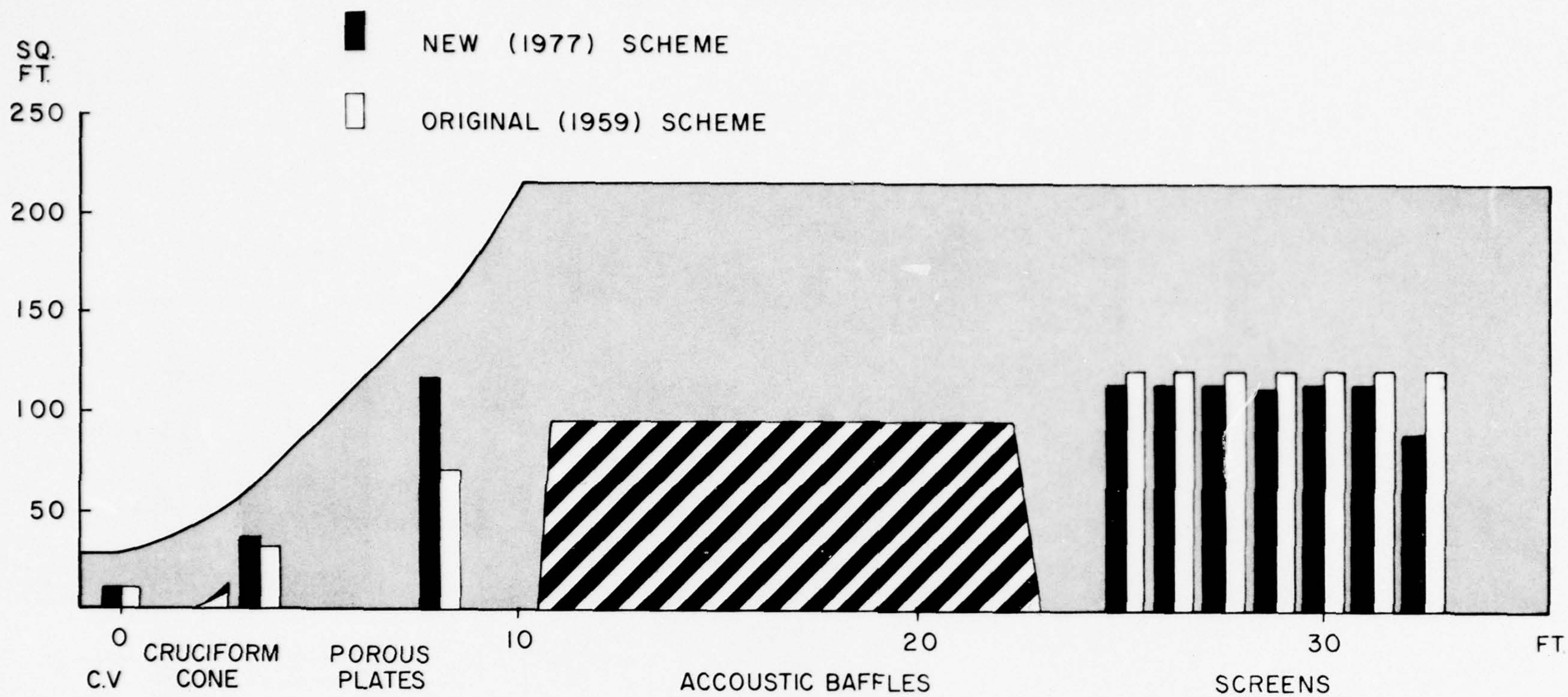

FIG. 5: AREA DISTRIBUTION AND BLOCKAGE OF INLET DIFFUSER-SETTLING CHAMBER

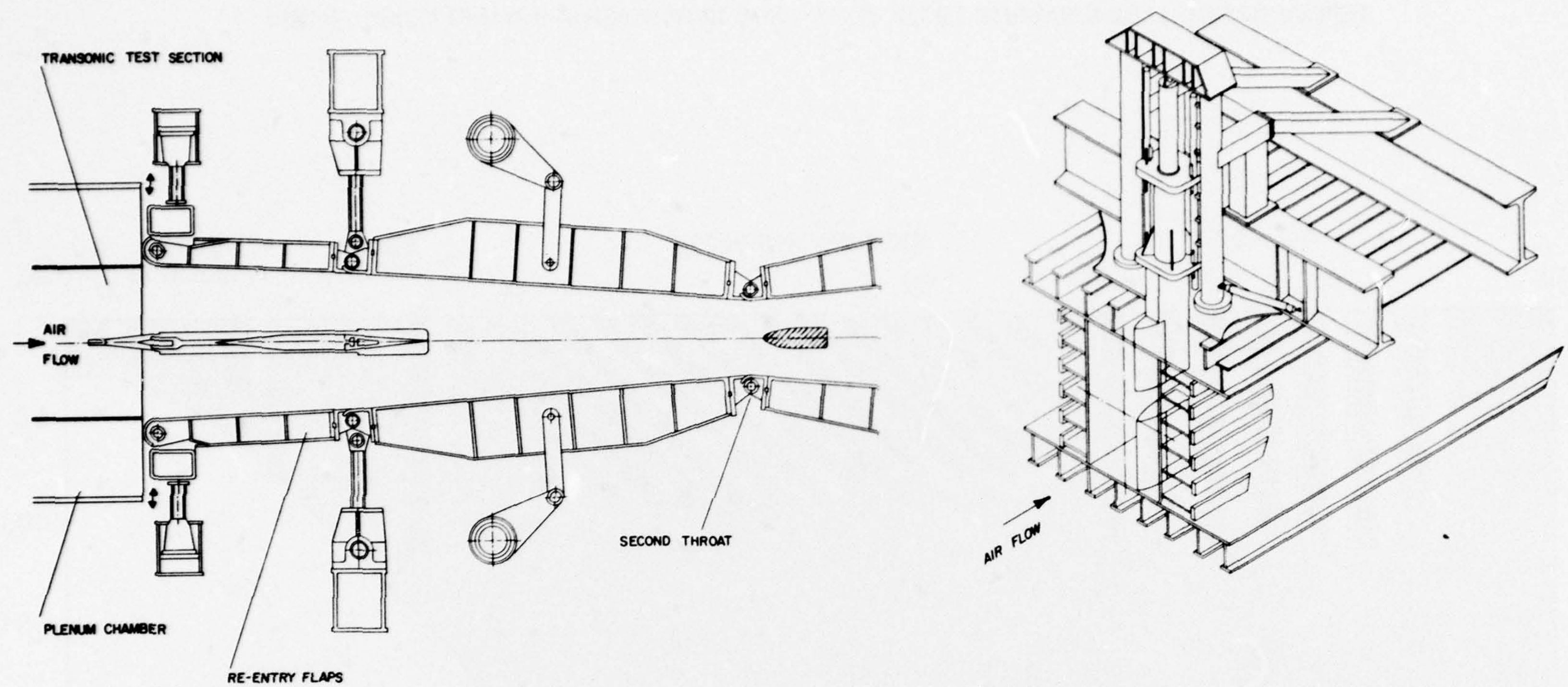

FIG. 6: CHOKE SYSTEM FOR MACH NUMBER CONTROL

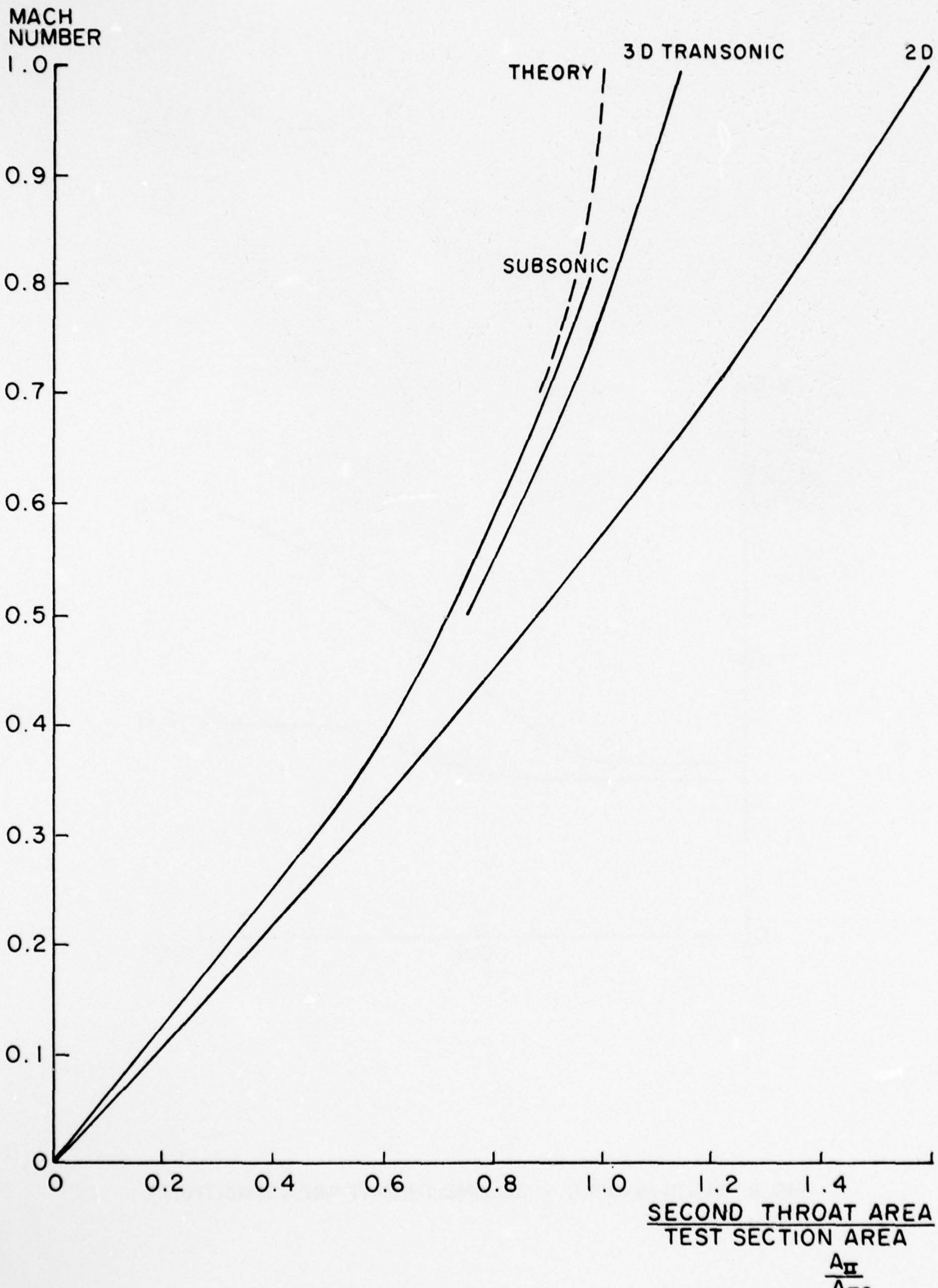

FIG. 7: TEST SECTION MACH NUMBER vs. AREA RATIO

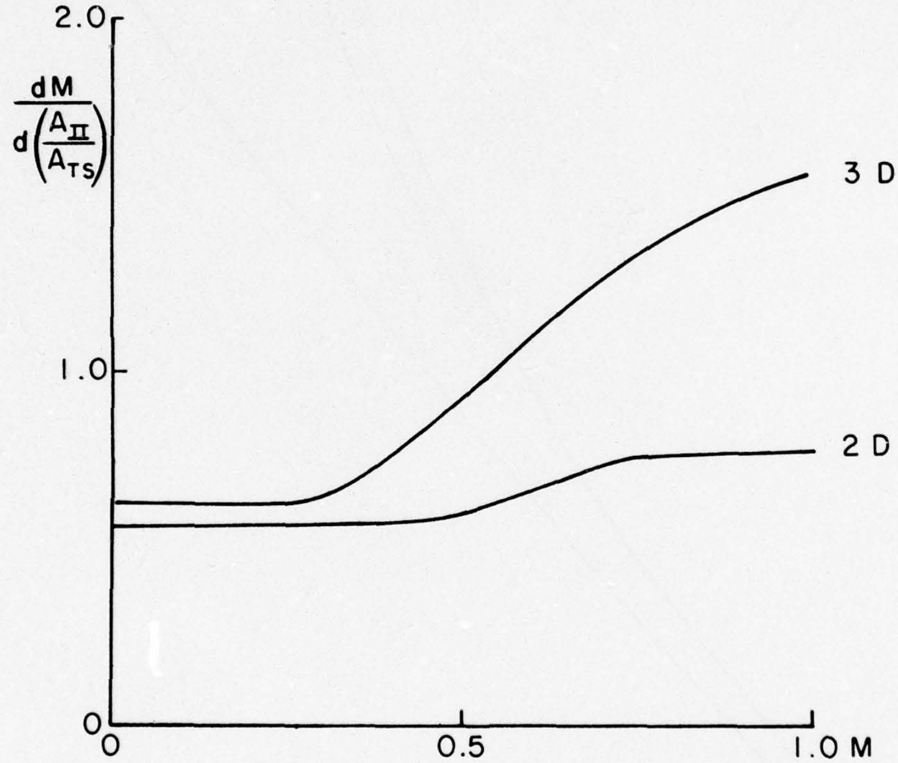

FIG. 8: MACH NUMBER – SECOND THROAT AREA SENSITIVITY

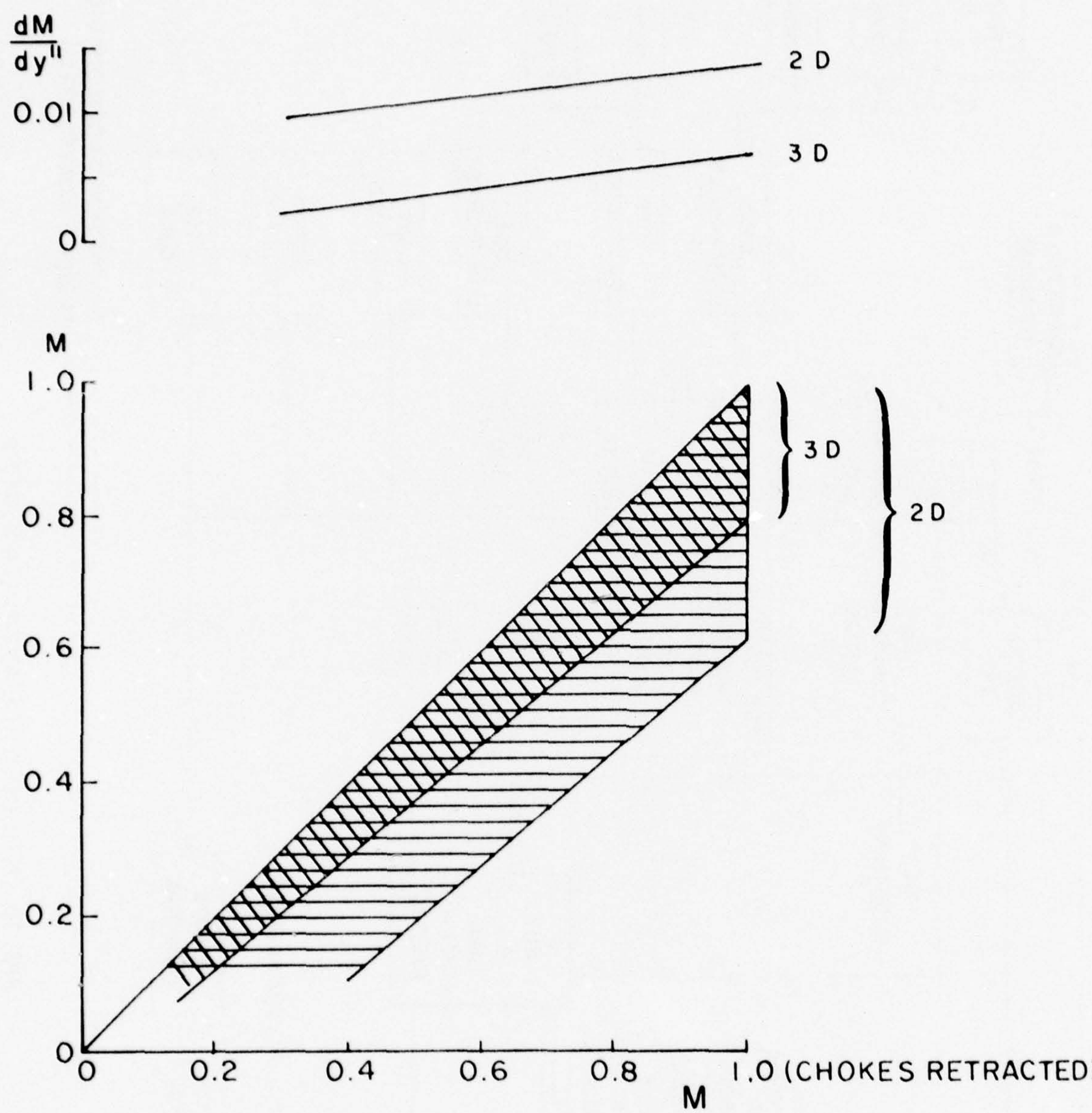

FIG. 9: OPERATING RANGE AND SENSITIVITY OF M-CONTROL SYSTEM

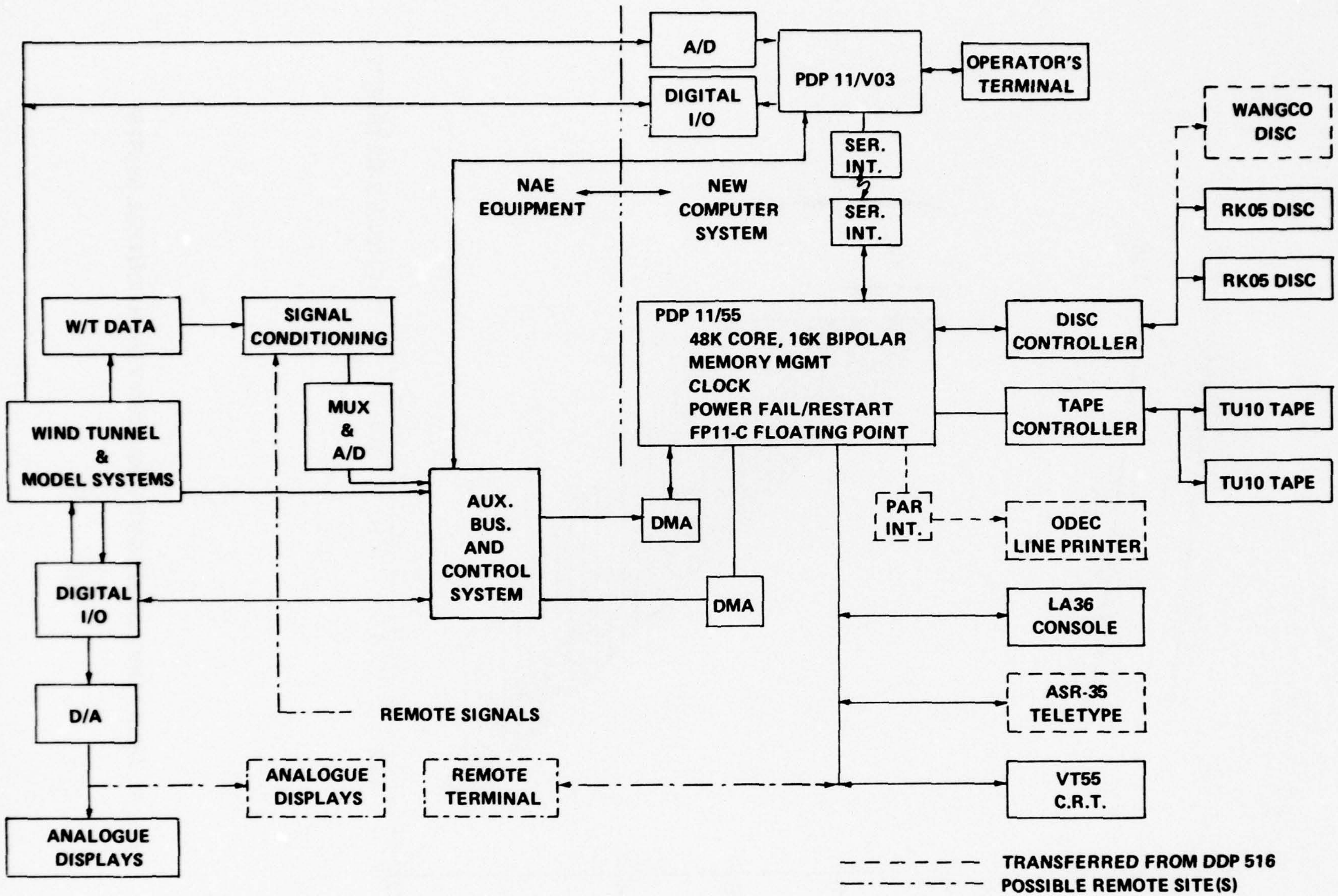

FIG. 10: NEW CONTROL AND DATA SYSTEM

CURRENT PROJECTS

Much of the work in progress in the laboratories of the National Aeronautical Establishment and the Division of Mechanical Engineering includes calibrations, routine analyses and the testing of proprietary products; in addition, a substantial volume of the work is devoted to applied research or investigations carried out under contract and on behalf of private industrial companies.

None of this work is reported in the following pages.

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ANALYSIS LABORATORY

AVAILABLE FACILITIES

This laboratory has analysis and simulation facilities available on an open-shop basis. Enquiries are especially encouraged for projects that may utilize the facilities in a novel and/or particularly effective manner. Such projects are given priority and are fully supported with assistance from laboratory personnel. The facilities are especially suited to system design studies and scientific data processing. Information is available upon request.

EQUIPMENT

1. An Electronic Associates 690 HYBRID COMPUTER consisting of the following:

   (a) PACER 100 digital computer

   - 32K memory
   - card reader
   - high speed printer
   - disc
   - digital plotter
   - Lektromedia interactive terminal

   (b) Two EAI 680 analogue computer consoles

   - 200 amplifiers including 60 integrators
   - 100 digitally set attenuators
   - non-linear elements
   - x-y pen recorders
   - strip chart recorders
   - large screen oscilloscope

   (c) EAI 693 interface

   - 24 digital-to-analogue converters
   - 48 analogue-to-digital converters
   - interrupts, sense lines, control lines

2. Hewlett Packard Model 3960 FM instrumentation tape recorder. IRIG standard, 4-track, 1/4-inch tape. Speeds: 15/16, 3-3/4 and 15 inches per second.

GENERAL STUDIES

A microprocessor-based function generator for the hybrid computer is being designed. A TI 990 development system has been obtained to be used for the project.

APPLICATION STUDIES

In collaboration with Aviation Electric Ltd., modeling work is underway in support of their advanced control concepts for both the small business jet engine and the helicopter engine. At present, the detailed model of a twin engine helicopter model is being used for detailed design studies and evaluation of hardware configurations.

In collaboration with Canadian Westinghouse Ltd., a study is being made of the fuel controller requirements for a new family of industrial gas turbines. A hybrid computer model has been assembled and is being used in the development of control system hardware.

In collaboration with Kendall Consultants Ltd., and SPAR Aerospace Products Ltd., a hybrid computer model of the remote manipulator arm being designed for the space shuttle is being assembled. The model is to include all allowable motions in three dimensions as well as arm flexibility effects. The 3 joint planar model is complete and arm algorithms are being evaluated.

In collaboration with the Railway Laboratory, a pilot hybrid computer model of the NRC roller rig for railway vehicle testing is being built as an aid in the design of the roller rig and its controls.

In collaboration with the Control Systems and Human Engineering Laboratory and the International Nickel Co., Ontario Division, an interactive computer model of a copper-nickel smelter is being developed to study material handling and scheduling in the plant.

In collaboration with Engine Laboratory a study is being made to develop a computer simulation of air cushion vehicles.

In collaboration with the Urban Transit Development Corporation and G.F. Crate Ltd., a model of an Intermediate Capacity Transit System was used to study various system designs and resulting operational performance.

In collaboration with Northern Telecom Ltd., an interactive computer program is being developed to schedule cable orders on cable stranding machines.

In collaboration with R.L. Crain Ltd., an interactive order streaming program for a print shop has been evaluated by the press co-ordinators.

In co-operation with Carleton University and Engine Laboratory a preliminary study is underway of a heavy equipment propulsion system using a co-rotating compressor.

In co-operation with Concordia University, a model of a heavy railroad freight vehicle is being assembled. Simulations of vehicle response to periodic and random excitations are to be conducted.

SYSTEM SOFTWARE STUDIES

An interactive package for setup and checkout of analogue computer circuits in a hybrid environment.

A simple graphics package for the LEK-104 terminal.

A preprocessor for hybrid computer model digital programs.

CONTROL SYSTEMS AND HUMAN ENGINEERING LABORATORY

INDUSTRIAL CONTROL PROBLEMS

Fluid sensor and control component research and development.

Interactive computer modeling applied to operations scheduling of large scale industrial plants and processes.

Development of CAMAC instrumentation for industrial control applications.

Engineering support to specific firms for the implementation of schemes for control and mechanization.

HUMAN ENGINEERING – BEHAVIOURAL STUDIES

Investigation of the control characteristics of the human operator and the basic phenomena underlying tracking performance.

Investigation of the nature of sensory interaction in human perceptual-motor performance.

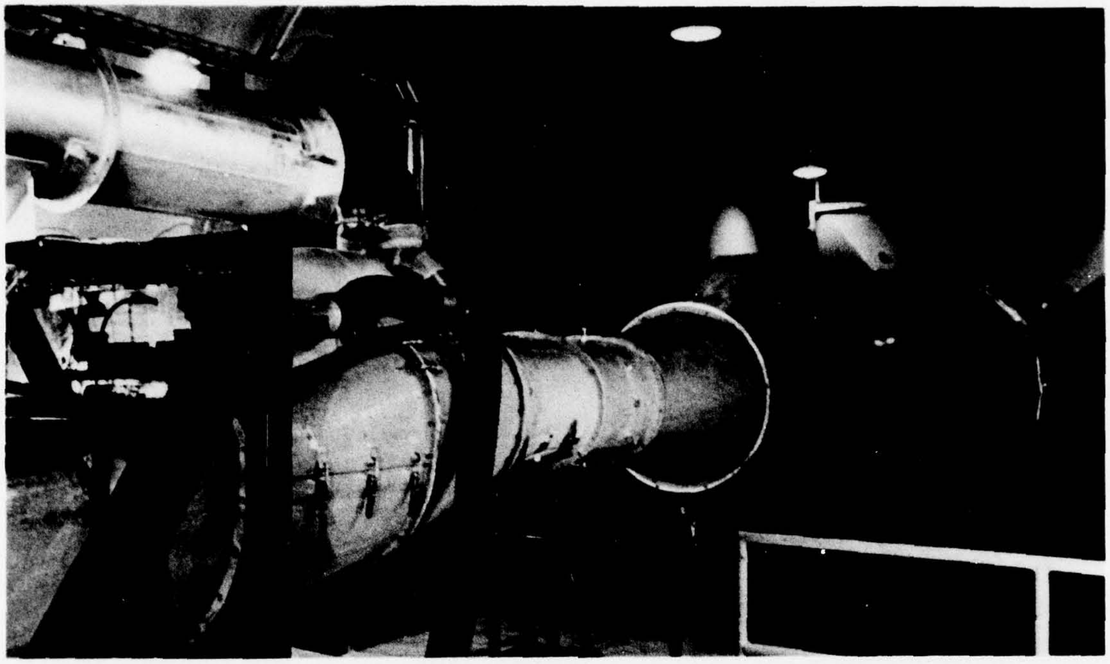
Investigation of the factors involved in the presentation and processing of information, particularly in relation to simulator design.

HUMAN ENGINEERING – MEDICAL AND SURGICAL

Development of heat exchangers for localized cooling of the spinal cord.

Measurement in-vivo of the mechanical impedance characteristics of skin and healed wounds.

Development of spinal cord monitoring device for use in clinical procedures involving the spinal column.



INSTALLATION IN ENGINE TEST CELL

CONTROL ROOM

Experimental Study of a PT6A-42 Gas Turbine Engine Installation Under Simulated Flight Icing Conditions.

ENGINE LABORATORY

DIVISION OF MECHANICAL ENGINEERING

ENGINE LABORATORY

HOSPITAL AIR BED

The Laboratory is supporting and directing an evaluation program involving air beds in hospitals. One experimental hospital air bed was designed, built, and is being used at the Hotel Dieu Hospital in Kingston, Ontario for clinical evaluation in the treatment of burns. A second air bed was purchased in England by the Victoria Hospital in London, Ontario, and was adapted by NRC to meet Ontario Hydro requirements.

Both air beds are being used successfully in different experimental programs. As a result of testing experience the NRC air bed has seen several useful modifications and is highly effective in defining important design parameters for future air beds. The evaluation has also led to a study of through-flow characteristics of various support fabrics, and hence to a new concept of support air bag structure. This new concept is now being tested clinically in Kingston.

GAS TURBINE OPERATIONS

An investigation of aircraft gas turbine engine operating characteristics is being conducted in conjunction with the Canadian Forces.

In conjunction with AETE, analysis of engine operating parameters during flight manoeuvres in a CF-5 aircraft is being carried out to evaluate proper functioning of the main fuel control unit.

Assistance has been given to the Canadian Forces in the development of an inlet protective system for sea-borne gas turbines operating in icing environments.

GAS TURBINE ICING INVESTIGATIONS

An icing research program was carried out on a Pratt and Whitney Aircraft of Canada PT6A-42 gas turbine, mounted in a Beech "Super 200" nacelle. The engine was protected by an inertial separation anti-icing system. An air ejector permitted simulated flight speeds of up to 210 mph (340 km/h) in the working section. The icing environment consisted of super-cooled water droplets, ranging from 15 to 40 micron median diameter, and snow.

Full-scale model icing tests on the inlet of a PT6A-27, intended for a small business twin aircraft, were conducted simultaneously. Air was induced through the compressor inlet and a bypass exit by an jeector system. Certification of the inertial separation system on the basis of model testing is being considered.

GAS TURBINE OPERATIONS

In co-operation with Davis, Eryou and Associates Ltd., and the Low Temperature and Fuels and Lubricants Laboratories of NRC, an investigation for the Department of National Defence was completed of the effect of different fuels on the starting characteristics of a small gas turbine engine after prolonged exposure at low temperatures.

AEROACOUSTICS

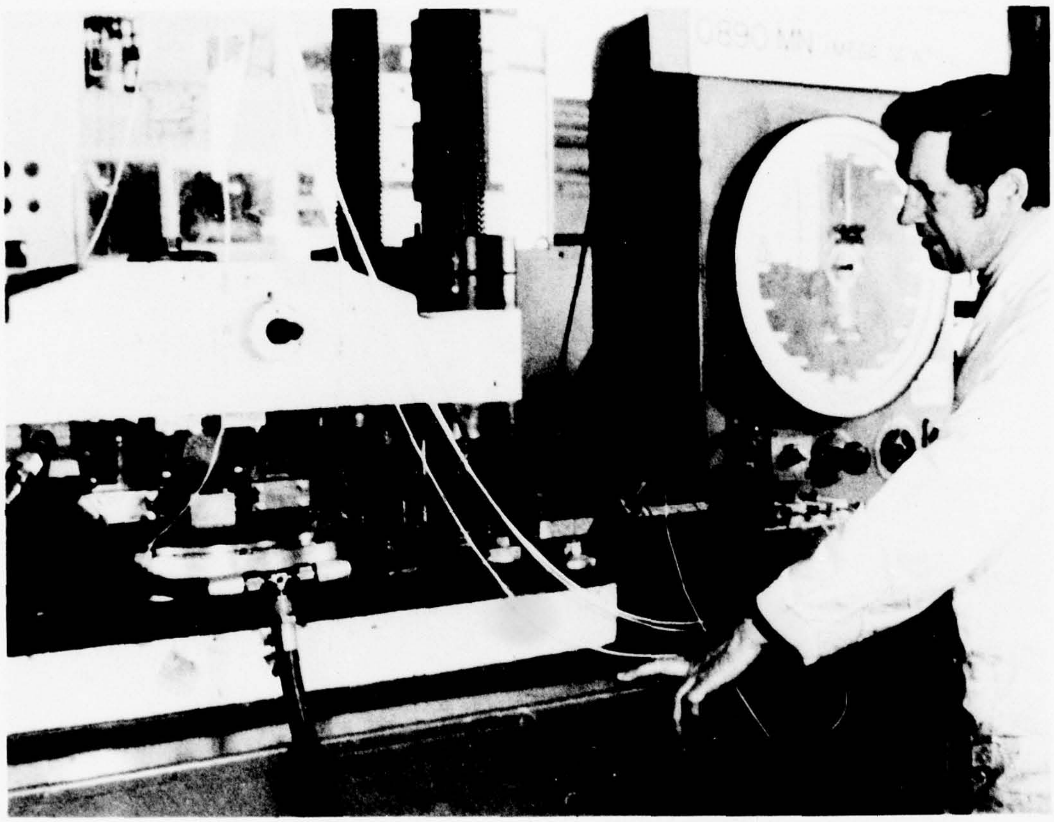
Evaluation of the stepped stator blade concept for reducing noise from single stage axial fans was completed in co-operation with the Division of Physics. Further experiments will be carried out with increased spacing between the rotor and stator blades.

A study of the noise characteristics of centrifugal fans and blowers is in progress. The experiments to study the effect of impeller blade shape and casing geometry on the aerodynamic performance and noise generation are being carried out in a 5-horsepower fan test rig. The method of fan noise measurements by duct wall flush-mounted microphone is under investigation.

ENGINE COOLING SYSTEM PERFORMANCE

In collaboration with Canadian industry an experimental study is being made of automotive cooling fan performance with the fan in its actual engine bay environment and subject to normal ram air conditions. The study involves both road and wind tunnel tests at full scale under not and cold radiator conditions. The test vehicle is typical of an intermediate size North American passenger car, and along with considerable in-vehicle instrumentation, is being provided by the industry for test purposes.

A good simulation of the road test cooling system aerodynamics has been achieved in the 10-ft. × 20-ft. test section of the Propulsion Wind Tunnel of the Division of Mechanical Engineering. Studies of component and system aerodynamic performance at ambient temperature conditions have been completed and the results are being assessed. Tunnel modifications to permit fully loaded, hot operation are being examined.



TEST OF HYDROSTATIC OIL BEARING FOR RAILWAY ROLLER RIG

AIR CUSHION VEHICLES

The study of ACV drag overland is continuing. The analysis of experimental data accumulated last year has enabled a rational treatment of the relation between lift and drag to be made. Two reports are being published on this work, over smooth ground and over dense vegetation. Further experimental work is planned to establish values for the coefficients proposed.

A handbook of design data on the performance aspects of ACVs is being compiled for early publication.

HYBRID DRIVE VEHICLE SIMULATION

An all-digital computer simulation of hybrid drive vehicles is being developed. A model of the accumulator system has been prepared and is being verified against an actual accumulator. Initially, a heat engine-hydraulic drive system has beem modeled and verified against a prototype system installed in the Fuels and Lubricants Laboratory. At present, the model can handle a spark ignition engine coupled to an automatic transmission in an automobile.

The model with data received on late model cars from manufacturers is being extended to include a variety of engine, transmission and vehicle combinations from compact size to full size vehicles.

AUTOMOTIVE FUEL ECONOMY

Equipment has been received and is being checked prior to running road tests in collaboration with the Metro Toronto Department of Roads and Traffic. The velocity profile of a float vehicle operating in traffic under different signal control patterns will be determined and used in the automotive computer model to calculate fuel consumption.

NRC-PRATT & WHITNEY HIGHLY LOADED TURBINE

The test cell has been prepared and the instrumentation of the test section is in progress. Trial assembly of the apparatus is being carried out without the nozzle and rotor test section.

ROTOR DYNAMICS

An experimental rig has been constructed to investigate techniques for improved vibration signal diagnosis from rotating machinery under a variety of operating and support conditions. Test rotors have been manufactured and the rig is being prepared for initial testing. Laboratory generated computer programs to predict critical speeds and mode shapes of the test shafts have been revised and improved for easier comparison with the experimental rotors.

HYDROSTATIC BEARINGS

The fabrication and testing of a prototype oil-lubricated hydrostatic bearing support system for the railroad roller test rig has been successfully completed. Manufacture of eight support pads based on the prototype is underway. Experimental and analytical work on air lubricated bearings and seals is continuing. Attention is being focused on aerostatic thrust bearings with one compliant surface.

VIBRATION MONITORING

An experimental rig has been assembled to allow the testing of rolling element bearings to failure. This rig will be used to compare current methods of vibration detection and their ability to discover incipient faults in rolling element bearings.

FLIGHT RESEARCH LABORATORY

AIRBORNE MAGNETICS PROGRAM

Experimental and theoretical studies relating to the further development of airborne magnetometer equipment and its application to submarine detection and geological survey, are currently in progress. The North Star flying laboratory has now been retired but analysis of magnetic data taken over east, west and Arctic coasts of Canada will continue for some time to come. Studies are continuing in very low frequency (VLF) and other navigation methods to support long range geophysical surveys. A Convair 580 aircraft to replace the North Star is currently being equipped with new magnetometer and computing systems.

INVESTIGATION OF PROBLEMS ASSOCIATED WITH V/STOL AIRCRAFT OPERATIONS

The Laboratory's Bell 205A1 variable stability helicopter is being employed in programs to investigate terminal area operational problems which are most severe for or peculiar to aircraft capable of low approach speeds. The 205, which is capable of measuring and recording the magnitude of the three components of motion of the atmosphere through which it flies, is employing this capability in a program of terminal area wind and turbulence documentation at the Rockcliffe STOLport. In a related program the 205 is being configured to simulate the flight characteristics and handling qualities of a powered-lift STOL transport aircraft. The effects of severe turbulence and strong wind shears on the approach handling qualities and operational envelope of such an aircraft are being evaluated by flying the simulated vehicle through naturally occurring atmospheric disturbances.

INVESTIGATION OF ATMOSPHERIC TURBULENCE

A T-33 aircraft, equipped to measure wind gust velocities, air temperature, wind speed, and other parameters of interest in turbulence research, is used for measurements at very low altitude, in clear air above the tropopause, in the neighbourhood of mountain wave activity, and near storms. Records are obtained on magnetic tape to facilitate data analysis. The aircraft also participates in co-operative experiments with other research agencies, in particular, the Summer Cumulus Investigation (see below). A second T-33 aircraft is used in a supporting role for these and other projects.

AIRCRAFT OPERATIONS

The Flight Recorder Playback Centre is engaged in the recovery and analysis of information from the various flight data recorders and cockpit voice recorders used on Canadian military and civil transport aircraft. The military systems are being monitored on a routine basis. Civil aircraft recorders are being replayed to investigate incidents or accidents at the request of the Ministry of Transport. Technical assistance is being provided during incident and accident investigations and relevant aircraft operational problems studied.

INDUSTRIAL ASSISTANCE

Assistance is given to aircraft manufacturers and other companies requiring the use of specialized flight test equipment or techniques.

INVESTIGATION OF SPRAY DROPLET RELEASE FROM AIRCRAFT

Theoretical and experimental studies of spray droplet formation from a high speed rotating disc have been conducted. Flight experiments utilize a Harvard aircraft modified to carry external spray tanks. Automatic flying spot droplet and particle analysis equipment is in operation for processing samples obtained in the laboratory and in the field by various agencies. The equipment has potentialities for the analysis of many unusual configurations provided that these may be photographed with sufficient contrast.

AUTOMOBILE CRASH DETECTOR

There is a need for a sensing device to activate automobile passenger restraint systems in incipient crash situations. Investigations are in progress to determine the applicability of C.P.I. technology to this problem.

SUMMER CUMULUS INVESTIGATION

At the request of the Department of the Environment flight studies of Cumulus cloud formations over Quebec and Ontario were instituted during the Summer of 1974. Instrumented T-33 and Twin Otter aircraft with a Beech 18 are being used to determine the properties of Cumulus clouds which extend appreciably above the freezing level. The measurements are being made to assess the feasibility of inducing precipitation over forest fire areas by seeding large cumulus formations. During 1975 a variety of cloud physics instruments were added to the Twin Otter, and special pods for burning silver iodide flares were attached beneath the wing of the T-33 turbulence research aircraft. The effects of seeding on the microstructure of individual cumulus clouds were studied in the Yellowknife area during the summers of 1975 and 1976 and in Thunder Bay in 1977. This project is planned to continue for several years.

FUELS AND LUBRICANTS LABORATORY

COMBUSTION RESEARCH

Experiments on fuel spray evaporation.

Investigation of handling and combustion problems involved in using hydrogen as a fuel for mobile prime movers.

Co-operative studies with Advisory Group for Aerospace Research and Development (AGARD) Working Group 11 to produce a report on aircraft fire safety.

EXTENSION AND DEVELOPMENT OF LABORATORY EVALUATION

Development of new laboratory procedures for the determination of the load carrying capacity of hypoid gear oils under high speed conditions and under low speed high torque conditions.

Evaluation of filter/coalescer elements for aviation turbine fuels.

Evaluation of longlife filter/coalescer elements from aviation turbine fuel service.

Water separation characteristics of aviation turbine fuels.

PERFORMANCE ASPECTS OF FUELS, OILS, GREASES, AND BRAKE FLUID

Investigation of laboratory methods for predicting flow properties of engine and gear oils under low temperature operating conditions.

Evaluation of static dissipator additives for distillate fuels.

Evaluation of properties of re-refined oils and by-product sludges.

Investigation of the use of anti-icing additive in aviation gasoline.

MISCELLANEOUS STUDIES

The preparation and cataloguing of infra-red spectra of compounds related to fuels, lubricants, and associated products.

The application of Atomic Absorption spectroscopy to the determination of metals in petroleum products.

Investigation of the stability of highly compressed fuel gases.

Analytical techniques for analysis of engine exhaust emissions.

Participation in the Canadian (CGSB), American (ASTM) and International (ISO) bodies to develop standards for petroleum products and lubricants.

The design and development of an internal combustion engine/hydraulic transmission hybrid power plant for the energy conserving car.

Further developments of specialized pressure transducers for engine health diagnosis and the development of diagnostic techniques and consultation with licencee in developing production methods for patented transducers.

Evaluation of various products, fuels, lubricants and hardware in respect of their effects upon overall vehicle fuel economy and energy conservation properties.

GAS DYNAMICS LABORATORY

V/STOL PROPULSION SYSTEMS

A general study of V/STOL propulsion system methods with particular reference to requirements of economy and safety.

INTERNAL AERODYNAMICS OF DUCTS, DIFFUSERS AND NOZZLES

An experimental study of the internal aerodynamics of ducts, bends, diffusers and nozzles with particular reference to the effect of entry flow distortion in geometries involving changes of cross-sectional area, shape, and axial direction.

SHOCK PRODUCED PLASMA STUDIES

A general theoretical and experimental investigation of the production of high temperature plasma by means of shock waves generated by electromagnetic and gasdynamic means, and the development of diagnostic techniques suitable for a variety of shock geometries and the study of physical properties of such plasmas.

NON-DESTRUCTIVE SURFACE FLAW DETECTION IN HOT STEEL BILLETS

An eddy-current surface flaw detector is being developed, using a special coil system by which a three-phase modulated R.F. signal is being electrically rotated round the billet at a rate given by the modulation frequency. The system displays the angular position of the flaw on a polar oscilloscope sweep or numerically, while the signal amplitude represents the depth of the flaw.

HIGH PRESSURE LIQUID JETS

High speed water jets generated by pressures in the range of 1000 to 60,000 psi can be used for cutting a wide variety of materials, e.g. paper, lumber, plastics, meat, leather, etc., and for cleaning surfaces such as masonry, rocks, tubular heat exchangers, etc. Nozzle sizes, depending on the application, are in the range from 0.002 to 0.15 in. diameter. A technique for manufacturing small nozzles in the range 0.002 to 0.015 has been developed using standard sapphire jewels available from industry. Larger orifices are manufactured and polished using standard shop procedures.

At present, the following investigations are active in the laboratory:

1. Intensive development of a rotating seal designed and developed in the laboratory. It appears to have great potential, especially for industrial cleaning, quarying and possibly for drilling operations.

2. Experiments on the fracturing of rocks using continuous and cavitating jets.

3. Experiments for clearing ice off runways and for cutting through thick ice ridges.

4. Experiments on the production of intermittent jets with high stagnation pressures.

Emphasis is now being placed on the study of effects produced by cavitating jets, how best to produce them and where they may be usefully applied.

HEAT TRANSFER STUDIES

Initial development of a temperature control thermosiphon for an electronic package has been successfully concluded. Life testing of this device has commenced.

An investigation of methods of increasing boiling and condensing heat transfer coefficients by treatment of the heat transfer surface has begun.

A co-operative project with the Division of Building Research will determine the usefulness of the thermosiphon as a ground heat source for a heat pump.

Work has started on extending the range of design information for use in air-to-air heat recovery units.

COMPUTATIONAL FLUID DYNAMICS

To support the experimental work, numerical simulations are being developed in three areas.

Single-pulse jets from vertically-accelerated liquid-filled rotating cones. This is a two-dimensional, axisymmetric, unsteady, incompressible flow problem with a free surface, where the liquid is subjected to large body accelerations.

Fluid dynamics of laser-produced plasmas. The phenomena are considered as two-dimensional, axisymmetric, unsteady, compressible flow problems in which real gas behaviour is considered. The approach, which uses Lagrangian formulation, has been used to calculate two cases:

(a) The fluid dynamics of a laser breakdown plasma, with the objective of explaining the mechanism of beam re-entry into the plasma when beam intensity is reduced.

(b) The interaction of a CO_2 laser beam with magnetically confined plasmas. This major problem is currently being studied numerically as part of a co-operative effort with the Aerospace Research Laboratory of the University of Washington.

Shock dynamics and fluid dynamics resulting from synchronized spark discharges on the axis and discharges on the perimeter of a cylindrical vessel containing hydrogen, to achieve high gas temperatures on the axis of the vessel.

GAS TURBINE BLADING STUDIES

A program on the theoretical and experimental study of the performance of highly loaded gas turbine blading has been undertaken as a collaborative program with industry and universities.

INDUSTRIAL PROCESS, APPARATUS, AND INSTRUMENTATION

There is an appreciable effort, on a continuing basis, directed towards industrial assistance. This work is of an extremely varied nature and, in general, requires the special facilities and capabilities available in the laboratory.

Current co-operative projects with manufacturers and users include:

(a) Flow problems associated with industrial gas turbine exhaust systems (Foster Wheeler).
(b) Combustion studies for industrial gas turbine applications (Westinghouse and Rolls-Royce).
(c) Application of thermosiphon as an energy conserving device in industrial applications (Dept. of Agriculture, Ministry of Transport, Farinon Electric, Chromalox Canada Ltd).
(d) Scaled model studies on steel and copper converters to establish relative performance and ceramic liner deterioration rates (Canadian Liquid Air and Noranda).
(e) High pressure water jet applications in industry (High Pressure Systems Ltd.).
(f) Scaled model studies to establish the performance of complex industrial flue systems with a view to establishing specific design and performance criteria. (Noranda and Inco Canada Ltd.).
(g) Model studies of internal flows in reactor hood and waste heat boiler (Noranda and Kennecott Copper Corp.).
(h) Test on Annubar flow metering system (A.E.C.L.).

HIGH SPEED AERODYNAMICS LABORATORY

RENEWAL OF THE TURBULENCE DAMPING SCREENS IN THE 5-FT. × 5-FT. WIND TUNNEL

This work was completed in February 1978. Inspection of the new installations and assessment of stresses on various components, after a fair number of runs, have shown comforting results. The wind tunnel is back in operation.

CALIBRATION OF THE 5-FT. × 5-FT. WIND TUNNEL'S TRANSONIC TEST SECTION

Measurements, identical in nature to those which were made before the dismantling of the tunnel in July 1977, were recently made.

Comparisons of stagnation pressure fluctuations, mean flow angles and also r.m.s. values of the fluctuating flow angles are available at nine stations (6 inch intervals) across the width of the test section. In addition some measurements were made with five pitot-static probes placed in the spaces between the acoustic baffles of the settling chamber.

Improvements in stagnation pressure fluctuations vary across the test section, ranging from a few percent at the centre to a factor of about 3 at the stations nearest the walls. The largest improvements for stations near the middle of the duct are seen for $M < 0.5$.

The short period fluctuations in mean flow angle have been considerably reduced through the refit and r.m.s. values of the fluctuating angles show the greatest improvement of any quantity, being less by up to factors of 5 across the entire width of the section.

The settling chamber results indicate that the changes to the flow diverting cone (increased angle) and the second perforated plate (increased blockage) have had the effect of making the outer regions of the inlet diffuser accept the highest flow velocities. The virtual interruption of flow near the center of the duct at a specific control value opening does not now occur.

SETTLING CHAMBER STUDY IN 5-IN. × 5-IN. WIND TUNNEL

Model tests have been conducted in the NAE pilot facility, to determine the effect of increasing the resistivity of the second porous (dished) baffle in the wide angle diffuser ahead of the stilling section, and the installation of "trimming" screen at the exit of the acoustic baffle geometry. Furthermore, studies of the effect of modifications to the cruciform-cone structure at the entrance of the wide angle diffuser on the settling chamber flow have also been conducted. Based on the results of these studies, certain revisions to the settling chamber of the 5-ft. × 5-ft. wind tunnel have been made, which we expect to considerably improve the flow distribution and to decrease the level of pressure fluctuations at the entry to the stilling section.

DATA SYSTEM IMPROVEMENTS ON 5-FT. × 5-FT. WIND TUNNEL

Modernizing and upgrading of the data system on the 5-ft. tunnel has been progressing slowly towards the new PDP 11/55 system under RSX11-M.

New amplifiers have been installed, increasing the number of channels available to 40 of high quality and 40 of lower quality. These amplifiers have gains ranging from 1 to 5000 and switchable front end filters with cutoffs from 3 Hz to 10 kHz. Self-checking, remote calibration and remote switch readouts are built in and will be used when the new system is installed sometime this fall.

At that time, improved direct digital I/O will be installed (for "status" type information) and a table-driven external multiple condition interrupt system should unload the processor significantly. This in turn should make possible on-line data reduction, which will be only partly available initially.

As part of the upgrading, a remote site capability will also be available at that time.

TWO-DIMENSIONAL TRANSONIC FLOW STUDIES

Efficient computer programs based on finite difference procedures are available for the design of supercritical airfoils and for the analysis of supercritical flow. A small disturbance transonic program has been developed and includes wind tunnel wall effects.

A new series of airfoil sections suitable for aircraft propellers is being investigated.

TRANSONIC EQUIVALENCE RULE INVOLVING LIFT

The classical area rule is well known and its application to wing-body design and drag reduction is demonstrated on many existing aircraft. Recent advances in transonic aerodynamic theory show that the classical area rule requires a modification to account

for lift. A series of experiments is being prepared in order to investigate these new concepts. The results of these experimental studies will provide criteria for wing body design with emphasis on drag reduction for aircraft cruising at transonic speeds.

STUDIES OF WING BUFFETING

Some preliminary studies of wing buffeting in wind tunnel tests have been carried out. The non-stationary random balance signals were analyzed in order to determine some unique features which are characteristic of buffet. Computer calculations of the buffet boundaries for three aerofoils (NACA 0012, RAE 103 and Shockless No. 1) show quite good agreement with flight and wind tunnel test data.

THEORETICAL AND EXPERIMENTAL STUDY OF JET NOISE

Further investigations of internal noise in a low speed jet are in progress. More detailed studies of the interaction of the transmitted sound with the jet flow and some statistical investigation of the multiple wave scattering by the turbulent eddies will be carried out. Some experiments on co-axial jets have been performed and measurements of pressure fluctuations in the turbulent shear layer have been undertaken. Mean flow velocity measurements in a jet have been carried out by the use of a Laser Doppler Velocimeter. A satisfactory aerosol generator has been built to seed the flow with di-phthalate (2-ethylhexyl) particles. Turbulence measurements are in progress.

REYNOLDS NUMBER EFFECTS ON TWO-DIMENSIONAL AEROFOILS WITH MECHANICAL HIGH LIFT DEVICES

A multi-component airfoil model, based on a supercritical airfoil, has been designed and manufacturing is in progress. The model will be equipped for pressure measurements on all components and provision is also made for boundary layer wake surveys in the vicinity of the airfoil surface. The model is part of a program aimed at a detailed analysis of 2-D high lift flow and the effect of Reynolds number on the optimum flap settings.

Work on an iterative solution of the compressible boundary layer flows about multi-element airfoil is continuing at the University of Manitoba.

HYDRAULICS LABORATORY

ST. LAWRENCE SHIP CHANNEL

Under the sponsorship of the Ministry of Transport, a study to improve navigation along the St. Lawrence River, using hydraulic and numerical modeling techniques.

NUMERICAL SIMULATION OF RIVER AND ESTUARY SYSTEMS

Mathematical models have been developed to simulate tidal propagation in estuaries, wave refraction in shallow water and littoral drift processes. The feasibility of using array processors to solve the hydrodynamic equations is presently under study.

WAVE FORCES ON OFF-SHORE STRUCTURES

Wave flume study to determine design criteria for off-shore structures, such as cooling water intakes or outfalls, mooring dolphins, drilling rigs, etc.

RANDOM WAVE GENERATION

A study of random waves generated in a laboratory wave flume by signals from a computer. Special attention is paid to the simulation of wave groups.

STABILITY OF RUBBLE MOUND BREAKWATERS

A flume study for the Department of Public Works to determine stability coefficients of armour units and the effect of a number of wave parameters on the stability of rubble mound breakwaters, including the effect of wave grouping.

WAVE LOADS ON CAISSON TYPE BREAKWATERS

A flume study for the Department of Public Works to determine the overall loading, as well as the pressure distribution on various Caisson-type breakwaters.

WAVE POWER AS AN ENERGY SOURCE

A general study to assess the wave power available around Canada's coast and to evaluate various proposed schemes to extract this energy. International co-operation is taking place through the International Energy Agency of OECD.

MOTIONS OF LARGE FLOATING STRUCTURES, MOORED IN SHALLOW WATER

A mathematical and hydraulic modeling program will be carried out to develop techniques and methods to forecast motions of, and mooring forces on large structures moored in shallow water.

CALIBRATION OF FLOW MEASURING DEVICES

Facilities to calibrate various types of low meters up to a maximum capacity of 5,000 gpm are regularly used for/or by private industry and other government departments.

POINTE SAPIN HARBOUR MODEL STUDY

A moveable bed hydraulic model is used to determine sedimentation patterns of Pointe Sapin Harbour, N.B., to define remedial works, reducing dredging requirements and improving the operation of this fishing harbour. The study is sponsored by the Small Crafts Harbour Branch of DFE, through Public Works, Canada.

TRANSPORT OF SAND ON BEACHES

A method has been developed for calculating rates of sand transport in the presence of waves, a modification of the Ackers and White method for river flows. A new flume was recently constructed in which the method can be tested.

BLUFFERS PARK MODEL STUDY

A hydraulic model study to design adequate entrance conditions to a new recreational harbour at Bluffers Park (Scarborough, Ont.) for Public Works, Canada.

LOWER CARAQUET MODEL STUDY

A hydraulic model study to investigate wave agitation at Lower Caraquet, N.B. for Public Works, Canada.

LOWHEAD VERTICAL AXIS WATER TURBINES

A research program will be started to investigate the feasibility of extracting power from water currents, by using low head, vertical axis turbines.

LOW SPEED AERODYNAMICS LABORATORY

WIND TUNNEL OPERATIONS

The three major wind tunnels of the laboratory are: the 15-ft. diameter, open jet, vertical tunnel, the 6-ft. × 9-ft. closed jet horizontal tunnel; and the 30-ft. V/STOL tunnel. During the quarter, programs undertaken included work for Canadair Limited, and the Wind Engineering Group of the Laboratory. Final performance specifications have been submitted to the Department of Supply and Services for a new wind tunnel data acquisition and control system to replace the present system which has been in service for 20 years. The contract is scheduled to be let by 15 May 1978.

WIND ENGINEERING

Measurements of wind properties are being continued on the Lions' Gate Bridge, Vancouver as part of an aerodyanmic investigation of the bridge. A fifth anemometer has been added to the four already distributed along the span. Outputs from the anemometers and two accelerometers that measure bridge motion are recorded by an automated system. The equipment has been serviced in preparation for the spring high wind season. Site assistance is being provided by Buckland and Taylor Limited, Vancouver.

Flow visualization studies were completed in the Flow Visualization Water Tunnel for the Aluminum Company of Canada Limited, of their bauxite ship unloader at Port Alfred, Quebec. Wind blown dust from the unloading operation is the cause of some pollution in the community and exhaust suction systems are being examined to minimize escape of dust from the unloader hopper.

A wind tunnel test was performed on a prototype Ski-Doo snowmobile to investigate the effect of air intakes on engine cooling. The work was done in the DME propulsion wind tunnel using a full-sized machine and running engine.

An investigation of the effect of trailer mounted refrigeration units was made for Thermo-King Corporation in order to quantify the full saving provided through the aerodynamic drag reduction they produce. The work was done using 1:10 scale truck models in the 6-ft. × 9-ft. wind tunnel.

FLUIDICS

Co-operative studies with D.G. Instruments of a 3-axis air velocity sensor are continuing using both NRC and industry developed concepts. Studies of vortex excitation of velocity sensor probes have been carried out in co-operation with Fluidynamics Devices Ltd. A program of applications of laminar flow in thin passages is being carried out in co-operation with the Control Systems and Human Engineering Laboratory of DME.

NUMERICAL METHODS

A correlational theory for the prediction of boundary layer transition has been devised and successfully demonstrated in some simple uses which are of interest for the design of airfoils.

The numerical methods are applicable to compressible flows involving heat and mass transfers at the boundaries.

VERTICAL AXIS WIND TURBINE

The 230 kW demonstration wind turbine, designed and built by Dominion Aluminum Fabricating Limited has been erected by Hydro Quebec and has begun experimental operation on the Magdalen Islands. DAF are now developing commercial turbines in the power range from about 5 to 50 kW. A small turbine built by Bristol Aerospace has been operating successfully, without maintenance, for over one year at an automatic meteorological station on the Beaufort Sea ice. Bristol are continuing development of turbines as power sources at remote sites.

AERIAL SPRAYING OF PESTICIDES

A new spray boom designed has been tested in co-operation with Conair Aviation (Abbotsford B.C.). This configuration will have significantly less aerodynamic drag than the present installation which is used on the DC-6B aircraft and is expected to save several hundred horsepower. The spray emission from the new configuration is currently being evaluated in flight and in the NAE 6-ft. × 9-ft. horizontal wind tunnel.

Theoretical and experimental studies are continuing on the effects of the vortex wake and other factors on the swath width of spray left by a low flying aircraft.

BOMBARDIER PROTOTYPE SKIDOO SNOWMOBILE
IN THE PROPULSION WIND TUNNEL OF
DIVISION OF MECHANICAL ENGINEERING,
FOR ENGINE COOLING STUDY

LOW SPEED AERODYNAMICS LABORATORY

NATIONAL AERONAUTICAL ESTABLISHMENT

LOW TEMPERATURE LABORATORY

RAILWAY CLIMATIC PROBLEMS

Under the auspices of the NRC Associate Committee on Railway Problems, Sub-Committee on Climatic Problems, a variety of analytical and experimental work is conducted on a continuing basis.

THERMAL PROTECTION OF TRACK SWITCHES

The use of heat to eliminate switch failures from snow and ice is a standard approach to this problem. Work has been carried out on improving the efficiency of forced convection combustion heaters and the means of distributing heat to the critical areas of a switch.

HORIZONTAL AIR CURTAIN SWITCH PROTECTOR

A non-thermal method of protecting a switch from failure due to snow has been undergoing development and evaluation. This method consists of high velocity horizontal air curtains designed to prevent the deposit of snow in critical areas of a switch. The tests conducted to date are especially encouraging with respect to yards and terminals. Additional evaluation is required for the line service application.

NEW RAILWAY SWITCH DEVELOPMENT

The ultimate solution to the existing problem of snow and ice failure of the point switch would appear to be replacement by a new design that is not subject to failure in this way. A switch has been designed, fabricated, laboratory tested and has now completed one winter season of field trials. The design involves only shear loading from snow and ice.

LOCOMOTIVE SANDING EQUIPMENT

An investigation into the various possible modes of failure of a locomotive sanding system resulting from low temperature has been undertaken. In addition to the expected failures resulting from moisture freezing in various parts of the pneumatic equipment, two other modes of failure are being investigated further.

HELICOPTER DE-ICING

A study of helicopter icing protection involving the evaluation of various systems (thermal, fluid, and self-shedding materials) and the development of de-icing control systems including ice detectors. The principles for a dynamic ice detector with high sensitivity to be used on helicopters are being investigated. Investigation of methods of establishing a rate function with the dynamic icing detection principle is being conducted.

MISCELLANEOUS ICING INVESTIGATIONS

Analytical and experimental investigations of a non-routine nature, and the investigation of certain aspects of icing simulation and measurement.

TRAWLER ICING

In collaboration with Department of Transport, an investigation of the icing of fishing trawlers and other vessels under conditions of freezing sea spray, and of methods of combatting the problem.

AIRBORNE SNOW CONCENTRATION

To provide statistical data on the airborne mass concentration of falling snow in order to define suitable design and qualification criteria for flight through snow, measurements of concentration and related meteorological parameters are being made.

SEA ICE DYNAMICS

Analytical and experimental work on the techniques of forming low-strength ice from saline solutions is being carried out in connection with proposed modeling studies of icebreaking ships and arctic port facilities.

An investigation is being made into the modeling of sea ice based on the freezing of aqueous solutions. The objective of the investigation is to improve the dynamic similarity in model testing in simulated sea ice.

MARINE DYNAMICS AND SHIP LABORATORY

HIGH SPEED

Several models in a systematic series have been studied and others are being prepared to determine their performance in still water and in waves.

COMBINATION FISHING VESSEL

Model tests are in progress on a new design of 70 ft. West Coast combination salmon and herring fishing vessel.

The basic hydrodynamic efficiency of the design has been investigated through resistance and self-propulsion tests in calm water and preparations are in hand on the most important aspects of the study. These concern the performance of the vessel and the safety against capsize in waves.

These seakeeping tests will be carried out in the 130 m. × 65 m. ×3.5 m. seakeeping and manoeuvring basin in early summer.

PATROL FRIGATE

The laboratory is making a major contribution to the design of the hull and propeller of a new Patrol Frigate.

The major characteristics of the hull were closely based on results of the systematic series of model tests for high speed ships being carried out at NRC. A 1/25th scale model is being made which will be used to establish not only predicted speeds and powers, but also to give information on the water flow around the hull so that bilge keels and propeller shaft supports and propellers can be optimally designed and fitted. The test program also includes seakeeping and manoeuvring tests to ensure that the proposed design will meet all hydrodynamic aspects of its specification.

ANTI-PITCHING

Reduction of ship motions is of major importance in the design of small fast warships. While toll stabilization is common, it is generally believed that pitch stabilization is not practical because of the large forces involved.

The laboratory is engaged in tests in which hydrofoil technology is being applied to anti-pitching fins. In a first series of tests a model, fitted with fins is to be run in calm water to determine the forces and moments acting for a range of attitudes of the hull. Later, tests in waves are to be carried out.

POLAR "10" ICEBREAKER

A model of a triple screw, polar class "10" icebreaker has been constructed in the laboratory. Extensive investigations are to be carried out in open water including resistance, self-propulsion, wake survey and wind milling studies. In addition, simulated ice-breaking load tests will be conducted.

DEVELOPMENT OF NON-AQUEOUS SOLUTION SYNTHETIC MODEL ICE

As is well known, the properties of full scale ice must be scaled down when carrying out model tests. To this end, extensive studies are being carried out of the physical characteristics and procedures for the manufacture of non-aqueous solution synthetic model ice for ship model experiments.

RAILWAY LABORATORY

RAILWAY STUDIES

As a continuation of the study of rail corrugation formation and to assist CP Rail with the measurement of rail geometry and forces, special equipment was provided and tests carried out on a coal car in the Rockies and on the CP track recorder car between Montreal and Ottawa. Analysis of the results continues at NRC.

Track force instrumentation is being developed for use in assessing experimental 100-ton freight car trucks in June with CP Rail and Transport Canada Research and Development Centre.

Lading securement studies have been conducted on the impact track for a Canadian public utility.

RAILWAY DYNAMICS BUILDING (U-89)

The track support structure has been installed and track side walkways are being constructed. The curve position control lever system designs for the rail track simulator have now been completed and these control levers are now being constructed by the manufacturing and technology centre. Various electronic, hydraulic and mechanical components for the railway car shaker system are also in the process of being designed.

The installation of electrical power services for the roller rig axle motor dirves and for the hydraulic shaker system power supply have been completed. Development of the speed and position control systems for the roller stands is proceeding.

GENERAL INSTRUMENTATION

The Laboratory is co-operating with the Marine Dynamics and Ship Laboratory in the development of the micro-processor controlled ship motion analyzer.

A non-contacting transducer is being developed to measure speed and displacement of ferromagnetic surfaces by correlating two magnetic noise signals.

An angle-of-attack real-time-processor is being developed for CP Rail.

A pendulous oil-damped, tilt insensitive accelerometer mount has been developed. Modifications to the prototype design of this mount have been made that will prevent, under severe operating conditions, damage to the accelerometer pivot support and/or windup of the signal conductors to the accelerometer.

MECHANICAL AIDS TO THE HANDICAPPED

Aid and advice is being given to the two Canadian firms licensed to build and market the Pocket Book Page Turner for the handicapped.

STRUCTURES AND MATERIALS LABORATORY

FATIGUE OF METALS

Studies of the basic fatigue characteristics of materials under constant and variable amplitude loading; fatigue tests on components to obtain basic design data; fatigue tests on components for validation of design; studies of the statistics of fatigue failures; development of techniques to simulate service fatigue loading.

RESPONSE OF STRUCTURES TO HIGH INTENSITY NOISE

Study of excitation and structure response mechanisms; study of panel damping characteristics and critical response modes; investigation of fatigue damage laws; industrial hardware evaluation; investigation of jet exhaust noise.

OPERATIONAL LOADS AND LIFE OF AIRCRAFT STRUCTURES

Instrumentation of aircraft for the measurement of flight loads and accelerations; fatigue life monitoring and analysis of load and acceleration spectra; full-scale fatigue spectrum testing of airframes and components.

ELECTRON FRACTOGRAPHY

Qualitative determination of fracture mechanisms in service failures; fractographic studies of fatigue crack propagation rates and modes.

METALLIC MATERIALS

Structure-property relationships in cast and wrought nickel-base superalloys. Studies of the consolidation and TMT processing of superalloy powders and compacts by hot isostatic pressing, hot extrusion and upset forging; studies on mechanical properties. Mechanics of cold isostatic compaction of metal powders, properties of hydrostatically extruded solids and compacts, extruded at pressures up to 1600 MN/m^2. Studies of the oxidation/hot corrosion behaviour of coated and uncoated refractory metals and superalloys.

MECHANICS AND THEORY OF STRUCTURES

Stresses in multi-cell caissons for marine structures. Stress concentrations at corners of box structures. Behaviour of plates under high-speed impact, with reference to bird resistance of aircraft windshields.

FLIGHT IMPACT SIMULATOR

Simulator developed and calibrated to capability of accelerating a 4-lb. mass to velocity of 1000 ft./sec. and an 8-lb. mass to velocity of 760 ft./sec.; operation on year-round basis achieved and includes use of temperature controlled enclosure from $-40°$ to $+130°F$; in addition to airworthiness certification program includes assessment of resistance to impact for materials and structural design for most types of viewing transparencies.

CALIBRATION OF FORCE AND VIBRATION MEASURING DEVICES

Facilities available for the calibration of government, university, and industrial equipment include deadweight force standards up to 100,000 lb., dynamic calibration of vibration pick-ups in the frequency range 10 Hz to 2000 Hz.

COMPOSITE MATERIALS

Studies of composites including resins, crosslinking compounds, polymerization initiators, selection of matrices and reinforcements, application and fabrication procedures, material properties, and structural design.

FINITE ELEMENT METHODS

Development and application of finite element methods to structural problems. Development of refined elements with curved edges. Development of methods for non-linear problems. Studies on the analysis of cracked members.

MOTOR VEHICLE SAFETY

In collaboration with Ministry of Transport, Road and Motor Vehicle Traffic Safety Branch, studies to determine the performance of headlights in the driver passing task are being carried out. Work is continuing on a system for studying driver performance and traffic quality by the analysis of automatically recorded vehicle control input and response data.

POLICE EQUIPMENT STANDARDS

The NRC/CACP Technical Liaison Committee on Police Equipment is a bilateral arrangement for bringing together police and government personnel to review police equipment requirements, equipment performance specifications, and conformance testing procedures. Work of the Committee is expedited by a permanent Secretariat which has a primary responsibility for continuity in the activities of a number of Sections, each dealing with a particular area of expertise, and for co-ordinating work and specialist contributions from various participating Departments and organizations.

UNSTEADY AERODYNAMICS LABORATORY

DYNAMIC STABILITY OF AIRCRAFT

Development of a forced-oscillation rolling apparatus.

Development of a translational-oscillation apparatus.

Vertical acceleration experiments.

Measurements of cross-coupling derivatives at high angles of attack.

Studies of the sensitivity of aircraft motion to aerodynamic cross coupling.

Development of hydraulic drive systems for high-load oscillatory apparatuses.

ATMOSPHERIC DISTRIBUTION OF POLLUTANTS

Instrumentation of a small mobile laboratory to measure airborne particulates and of an aircraft to detect atmospheric tracers.

Use of the above detection system to measure the vertical spread of a pollutant in a polar atmosphere during the AES pilot study of polar meteorology on Lake Simcoe.

Analysis of the downwind vertical spread and turbulent deposition of gaseous and aerosol pollutants from sources near the ground, with special emphasis on the effect of droplet evaporation.

TRACE VAPOUR DETECTION

Development of highly sensitive gas chromatographic techniques for detection of trace quantities of vapours of pesticides, explosives and fluorocarbons.

Sensitivity evaluation of commercially available explosive detectors.

Development of stopped-flow and continuous-flow vapour concentrators.

Testing of biosensors.

WORK FOR OUTSIDE ORGANIZATIONS

Damping and cross-coupling experiments for NASA.

Feasibility and design studies for NASA.

Aircraft-security feasibility studies for Transport Canada.

Feasibility studies for DSMA, Toronto.

WESTERN LABORATORY (VANCOUVER)

PRACTICAL FRICTION AND WEAR STUDIES

Various laboratory simulations of practical tribological systems to study friction, wear and lubrication behaviour of lubricants and bearing materials in response to specific external requests. For example, an investigation of the lubricity of methanol and means of improving same by the use of appropriate additives is currently in progress.

FUNDAMENTAL STUDIES IN TRIBOLOGY

Investigations of the low stress abrasive wear behaviour of glassy and other carbons and hard ceramic materials in relation to their microstructure and mechanical properties.

A special rolling contact apparatus is being designed that will allow experimental studies of the mechanisms of rail and wheel wear, and lubrication to be made in the laboratory.

LUBRICANTS

Development of a rapid moisture corrosion test for gear lubricatns as an alternative to the present CRC 633 test.

PRACTICAL STUDIES OF BEARINGS AND SEALS

The construction of a machine to test the effectiveness of the lubrication system of locomotive traction motor support (journal) bearings at low temperatures is being completed.

EXPERIMENTAL STRESS ANALYSIS

Using brittle lacquer and strain gauge techniques, stress distrubitions and maximum stress magnitude were measured in the casing of a prototype rotary vane ship's steering gear. The data obtained was used to check the validity of the design stress analysis procedure.

INSTRUMENTATION

Circuits were designed and constructed to provide suitable chart recorder signals for speed and coefficient of friction measurements on the laboratory's pin-on-disc friction and wear tester.

Transducers and signal conditioning units were designed and constructed to measure force, hydraulic pressures, steering torque and rudder angle for a series of tests being conducted by a local manufacturer of marine steering gears.

DIGITAL SYSTEMS

A semiconductor PROM circuit board and programming system has been developed to store the operating system and major utility programs for the Western Laboratory's mini-computer data logger.

NUMERICAL CONTROLLED MACHINING

Technical assistance on this subject is being provided to firms and other institutions in Western Canada which are considering the purchase of numerically controlled machines to improve their production efficiency. Seminars are held to explain the fundamentals of numerical control and programming and the laboratory's 3-axis NC milling machine is used to machine demonstration batch quantities of typical components for interested companies. Recently, the use of NC machining in the production of a mold for casting rock drilling bits has been demonstrated.

Use is being made of computer assisted programming and punched tape preparation as a means of reducing manual programming time for items requiring a large number of geometrical statements.

LOW TEMPERATURE TEST FACILITY

The laboratory's large low temperature test facility is being used by a private laboratory to test oil-seawater separation equipment under arctic conditions.

PUBLICATIONS

National Aeronautical Establishment

LR-595 FORGING BEHAVIOUR OF SUPERALLOY COMPACTS AND COMPOSITES.

A. Kandeil, J-P. Immarigeon, W. Wallace, National Aeronautical Establishment, February 1978.

The forging behaviour of hot isostatically pressed nickel-base superalloy (Mar M200) compacts, reinforced with 40% volume fraction of tungsten wires, has been examined and compared with that of the non-reinforced alloy matrix by means of isothermal and isostrain-rate compression.

Under identical working conditions, peak flow stresses for the composite specimens are up to 4 times those for the non-reinforced matrix. Furthermore the strain rate sensitivity of the composites is approximately half that of the superplastic matrix. A rationalization of these differences is presented.

Forming limit criteria for the composites are examined. A model is considered which predicts an upper bound forming limit beyond which severe damage is introduced into the composite. In the present case, the maximum strain achievable is predicted and shown to be approximately 0.34. At lower strains, formability is shown to be further limited by void nucleation at the tensile poles of the wires, normal to the loading direction. Means of improving the formability, which is controlled by the strength of the wire/matrix interface relative to that of the matrix, are discussed.

LABORATORY TECHNICAL REPORTS

National Aeronautical Establishment

LTR-HA-6 Brown, D.

Information for Users of the National Research Council's 5-ft × 5-ft Blowdown Wind Tunnel at the National Aeronautical Establishment. Third edition.
September 1977.

LTR-ST-944 Kulschyski, R.

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